ℙrinciples of ℂomputer ℙrogramming

https://princomp.github.io/docs/about/credits#authors

2025-05-16

# Foreword

Welcome to the course resources book to teach principles of computer programming using C#. This resource is accessible on-line at <https://princomp.github.io/>, and [the Credits section below](#credits) gives more detail on how this resource was developed and why.

This resource should *not* be read linearly: the [Computers and Programming section](#computers-and-programming) is where the actual content begins, the sections before it mostly describe how to use this resource, how to reach out for help, etc.

The source for this book is freely accessible at <https://github.com/princomp/princomp.github.io>, head there or at <https://princomp.github.io/docs/about/credits#authors> to find how to reach the maintainer(s) of this resource.

# Credits

## Purpose

This website contains all the resources to learn the principles of computer programming using C#. It is used in the delivery of CSCI 1301 - Principles of Computer Programming I and CSCI 1302 - Principles of Computer Programming II in the [Bachelor of Science in Computer Science](https://www.augusta.edu/ccs/bs-cs.php) at [Augusta University](https://www.augusta.edu), and contains practical guides and additional resources for students and instructors.

## Authors

At the time of writing, this resource is actively maintained [Clément Aubert](https://spots.augusta.edu/caubert/#contact). Additional contributions, by [(under)graduate course assistants](file:///C:\docs\academic_life\ca) and other contributors, are [tracked by version control](https://github.com/princomp/princomp.github.io/graphs/contributors).

Some of the material originated from discussion, handouts and contributions by [Clément Aubert](http://spots.augusta.edu/caubert/), [Aubrey Bryant](https://www.linkedin.com/in/aubrey-bryant-61898176), [Michael Dowell](https://spots.augusta.edu/mdowell/), [Richard DeFrancisco](https://www.augusta.edu/faculty/directory/view.php?id=RDEFRANCISCO), [Onyeka Ezenwoye](https://www.augusta.edu/faculty/directory/view.php?id=oezenwoye), [Leszek Gasieniec](https://cgi.csc.liv.ac.uk/~leszek/), [Reza Rahaeimehr](https://www.augusta.edu/faculty/directory/view.php?id=RRAHAEIMEHR), [Neea Rusch](https://nkrusch.github.io/), [Edward Tremel](https://edwardtremel.com/) and [Paul York](https://www.augusta.edu/faculty/directory/view.php?id=pyork1).

Additionally, the [School of Computer & Cyber Sciences](https://www.augusta.edu/ccs/)’s past and present [academic advisors](https://www.augusta.edu/ccs/faculty.php#administration), Laura Austin, Denise Coleman, Markus Bacha, and Wennie Squires, and communications & marketing specialist, Haley Bourne, improved the [Academic Life](file:///C:\docs\academic_life) notes through their suggestions and references.

## Supports

The first source of support is the constant stream of feedback we receive from students and users: thank *you*.

This project has been monetarily supported by an [Affordable Learning Georgia](https://www.affordablelearninggeorgia.org/) [Transformation Grants](https://www.affordablelearninggeorgia.org/grants/overview/) ([Proposal 571](https://www.affordablelearninggeorgia.org/assets/documents/571-proposal.docx)) and a Continuous Improvement Grant (M260).

[](https://www.affordablelearninggeorgia.org/)

This project also received the support of [Augusta University](https://www.augusta.edu/)’s [School of Computer and Cyber Sciences](https://www.augusta.edu/ccs/) and [Center for Instructional Innovation](https://www.augusta.edu/innovation/).

## Tools

We strive to prioritize open-source software when possible, and occasionally contribute to them.

### Software

This website uses different technologies.

* The markdown source code is converted to (a slightly different) md, pdf, odt and docx formats thanks to [pandoc](https://pandoc.org/) and [pandoc-include](https://github.com/DCsunset/pandoc-include) (among other lua filters).
* The pdf format is compiled using [XeLaTeX](https://tug.org/xetex/).
* The source code is highlighted thanks to [Pygments](https://pygments.org/).
* The website is powered by [quartz](https://quartz.jzhao.xyz/).

More details on the tools we use and how this resource is made can be found in [dev. guide](file:///C:\Users\NAFAHA\Downloads\M260-materials\dev_guide).

### Fonts

We use the [URW Gothic](https://fontesk.com/gothic-typeface/) and [Hack](https://sourcefoundry.org/hack/) (inspired by the [DejaVu](https://sourcefoundry.org/hack/) font) fonts. Those fonts have been specially selected for their legibility and [lower impact on environment](https://en.wikipedia.org/wiki/Century_Gothic#Printer_ink_usage).

### Services

The source code and the website are graciously hosted and built by [github](https://github.com/).

## License

This work is under [Creative Commons Attribution 4.0 International](https://creativecommons.org/licenses/by/4.0/). Concretely, this means that you are free to:

* Save, print, copy and redistribute the entirety of the resources presented here,
* Modify them as you see fit,

as long as you give proper credit and keep the same license .

Please refer to [our license file](https://github.com/princomp/princomp.github.io/blob/main/license.md) for the details of this license .

# Contributing

## How can I contribute?

### If you are a student

We would like to hear your thoughts on this resource to understand how to make it better for you and your fellow students. If you encounter a mistake, run into an issue while using the resource, or find it missing something important, you can contribute by providing feedback in one of the following ways:

* talk to your instructor about the issue
* talk to your section’s UCA about the issue
* leave feedback on this website on the page where you notice the issue
* [Open an issue](https://github.com/princomp/princomp.github.io/issues/new/choose)
* print the resource and identify the issue, then hand it to your instructor or UCA

If you have suggestions on how to make it better, we encourage you to share those ideas too.

### If you are an instructor

You will need to have a [Github account](https://github.com/join). Next contact any of the [authors](file:///C:\Users\NAFAHA\Downloads\M260-materials\credits#authors) of this resource over email, provide your Github username, and request an invitation to be added to the instructors team.

### If you are a UCA

You will need to have a [Github account](https://github.com/join). Next ask your course section instructor to invite you to the 1301 UCAs team. Your instructor needs your Github username to send you the invitation.

### If you are an outside collaborator

When you have identified a mistake in this resource and want to notify the authors, leave feedback on this website on the page where you notice the issue or [open an issue](https://github.com/princomp/princomp.github.io/issues/new/choose) explaining the issue.

If you want to make edits yourself, you can [fork](https://github.com/princomp/princomp.github.io/fork) the source code, make edits, then open a [pull request](https://github.com/princomp/princomp.github.io/pulls) for us to review.

## Next steps for editors

If you are looking to edit this resource and making your first contribution, read through the [dev. guide](file:///C:\Users\NAFAHA\Downloads\M260-materials\dev_guide). It explains:

* how to locate different resources
* how to edit the resources
* how to label content

Following the [dev. guide](file:///C:\Users\NAFAHA\Downloads\M260-materials\dev_guide) will help to ensure your edits meet the expected quality guidelines and can be integrated into the existing resource with ease.

# Developer’s Guide

This guide explains how this resource is organized, how it is built and deployed, and how to maintain this resource. It is intended to be comprehensive, but should most likely be read only after having read our [contributing](https:/princomp.github.io/docs/about/contributing) and [UCA](https:/princomp.github.io/docs/academic_life/uca_guide#editing-the-resources) guides.

## Resources Organization Overview

### Folders and Files

The [source code repository](https://github.com/princomp/princomp.github.io)’s main branch is organized as follows:

| path | description |
| --- | --- |
| .github/ | github templates and configuration for github actions |
| misc/ | resources that need to be either integrated into the resource, or discarded |
| source/ | source for the material |
| licence.md | license file |
| readme.md | presentation of the repository |

The source/ folder contains the following:

| path | description |
| --- | --- |
| code/ | code examples (snippets and projects) |
| docs/ | additional helpful documentation |
| solutions/ | exercises (*with* solution) |
| fonts/ | the fonts (redistributed with permission) used by this resource |
| img/ | images, sometimes with their LaTeX source code |
| labs/ | lab exercises |
| lectures/ | lecture notes |
| projects/ | projects (homework) |
| slides/ | slides |
| templates/ | templates and filters used for building this resource |
| diag/ | Diagrams |
| vid/ | video files |
| .mermaid-config.json | Mermaid configuration file |
| Makefile | makefile used to compile this resource |
| index.md | website index page |
| order | file used to specify the order onthe website’s menu and the book |
| tags | list of tags |

### Building and Deploying

The content is [built and deployed](#building-and-deploying) in two phases:

* [Running make all in the source/ folder](#building-all-resources) will create a content/ folder at root level containing:
  + one .md file per .md file in the source/ folder (in the same location: source/labs/If.md is compiled to content/labs/If.md), resulting from [pandoc](https://pandoc.org/)’s conversion,
  + one .pdf, .odt and .docx file per .md file (with the exception of the index.md files) in the source/ folder (in the same location: source/labs/If.md is compiled to content/labs/If.pdf), resulting from [pandoc](https://pandoc.org/)’s conversion,
  + some files from the img/, slides/ and vid/ folders, copied selectively (for example, only the .jpeg, .png, .pdf, .svg and .gif files are copied from the img/ folder),
  + the .woff and .woff2 files copied from the fonts/ folders,
  + a code/projects/ folder containing, for each Program.cs file contained in a source/code/projects/x/y, a x.zip archive containing a C# project including Program.cs along with some (optional) class file,
  + a web-order.ts file, compiled from the source/order file, that fixes the order used by the website in the menu,
  + a book.html, a book.pdf, a book.html and a book.docx file resulting from [pandoc](https://pandoc.org/)’s conversion of the .md files contained in the SOURCE\_BOOK’s makefile variable (containing all the .md files in the source/docs/ and source/lectures/, in the order fixed by the order file).
* Then, using the files in the generated content/ folder, a website is built using [quartz](https://quartz.jzhao.xyz/) and deployed to <https://princomp.github.io/>. This is achieved mainly thanks to the .github/workflows/build\_and\_deploy.yaml file and [github’s actions](https://docs.github.com/en/actions).

### Tools, Briefly

This resource is mainly developed and powered using

* [git](https://git-scm.com/)
* [pandoc](https://pandoc.org/installing.html)
* [make](https://www.gnu.org/software/make/)
* [python](https://www.python.org)
* [quartz](https://quartz.jzhao.xyz/),
* [github’s actions](https://docs.github.com/en/actions).

But note that knowing git and markdown are enough to contribute on-line through the [github repository](https://github.com/princomp/princomp.github.io).

While most of those tools are standard (with the exception of quartz, but it relies itself on the standard [Node](https://nodejs.org/) and npm technologies), we acknowledge that

1. It is challenging to understand that many different technologies,
2. We should strive to welcome contributions from collaborators not familiar with them,
3. Our set-up is unique in some respects.

This guide tries to alleviate some challenges resulting from this overall unique and diverse resource organization. For more details about our tools, please refer to the [Installing dependencies](#installing-dependencies) and [Repository Maintenance](#repository-maintenance) sections.

### Locating Resources

To obtain the latest version of this resource, you can either

* visit the accompanying website [princomp.github.io](https://princomp.github.io),
* download [the latest version of the built resource](https://github.com/princomp/princomp.github.io/releases/download/latest/release.zip),
* clone [our repository](https://github.com/princomp/princomp.github.io/).

This resource is an extension of [csci-1301.github.io/](https://csci-1301.github.io/), please refer to [their user guide](https://csci-1301.github.io/user_guide.html#locating-course-resources) for more information about it.

## Editing Resources

If you are new to this project, first read through [Contributing Guidelines](file:///C:\contributing) to learn how you can contribute to the improvement of this resource, and if applicable, how to join a contributing team.

### Best practices for all forms of content

#### Inclusivity

Follow the [IT Inclusive Language Guide](https://itconnect.uw.edu/guides-by-topic/identity-diversity-inclusion/inclusive-language-guide/) from the University of Washington:

use gender-neutral terms; avoid ableist language; focus on people not disabilities or circumstances; avoid generalizations about people, regions, cultures and countries; and avoid slang, idioms, metaphors and other words with layers of meaning and a negative history.

Typically, we recommend using

* “unethical hacker” instead of “black hat”,
* “main” instead of “master”,
* “blank space” instead of “white space”,
* “display on the screen” instead of “printing”,
* etc.

In doubt, please start by referring to [this list of problematic words and phrases](https://itconnect.uw.edu/guides-by-topic/identity-diversity-inclusion/inclusive-language-guide/#list).

#### Structure for accessibility

* All resources are titled
  + title each markdown document by having one (and only one) title at top level (that is, using #),
  + use subtitles when appropriate,
  + title all images with a descriptive title and add an alt-tag,
  + title all code blocks in labs and lecture notes.
* All resources are labelled when applicable, see [content labelling](#content-labelling) for more details

Resources to assess accessibility:

* [Affordable Learning Georgia’s guide](https://alg.manifoldapp.org/projects/oer-accessibility-series-and-rubric)
* [Specific Review Standards from the QM Higher Education Rubric](https://www.qualitymatters.org/sites/default/files/PDFs/StandardsfromtheQMHigherEducationRubric.pdf)
* [UWG Accessibility Services’s guide](https://docs.google.com/document/d/16Ri1XgaXiGx28ooO-zRvYPraV3Aq3F5ZNJYbVDGVnEA/edit?ts=57b4c82d)
* [Penn State’s recommendations for alternative text and complex images.](https://accessibility.psu.edu/images/)
* [WebAim Color Contrast Checker](https://webaim.org/resources/contrastchecker/)
* [WebAIM (Web Accessibility In Mind)](https://webaim.org/)

#### Markdown

Text documents are written using [standard markdown syntax](https://commonmark.org/). More precisely,

* in the commonmark\_x+pipe\_tables+emoji format, that is, [in commonmark’s markdown (“with many pandoc extensions”)](https://pandoc.org/MANUAL.html#markdown-variants), using (among others) the [emoji](https://pandoc.org/MANUAL.html#extension-emoji) and [pipe\_tables](https://pandoc.org/MANUAL.html#extension-pipe_tables) [extensions](https://pandoc.org/MANUAL.html#extensions)),
* using the [pandoc-include](https://github.com/DCsunset/pandoc-include) filter,
* and using [custom](https://github.com/princomp/princomp.github.io/tree/main/source/templates/filters) filters that sets all the [code blocks](https://github.com/princomp/princomp.github.io/blob/main/source/templates/filters/default-code-class-block.lua), or [all the code block and inline code](https://github.com/princomp/princomp.github.io/blob/main/source/templates/filters/default-code-class-block-inline.lua)’s syntax highlighting to C# by default.

Because of the way the markdown is processed, please refrain from using the “ and ” characters: pandoc will automatically convert " into language-appropriate quotes for us.

##### Callouts

As discussed [in this issue](https://github.com/princomp/princomp.github.io/issues/2), [callouts (a.k.a. alerts)](https://docs.github.com/en/get-started/writing-on-github/getting-started-with-writing-and-formatting-on-github/basic-writing-and-formatting-syntax#alerts) are not fully supported by pandoc, so a workaround is to use instead the following syntax:

| ⚠ Warning |  
|:---------------------------|  
| A warning |

| 💡 Tip |  
|:---------------------------|  
| A tip |

| ❗Important |  
|:---------------------------|  
| Something important |

which are rendered as

| ⚠ Warning |
| --- |
| A warning |

| 💡 Tip |
| --- |
| A tip |

| ❗Important |
| --- |
| Something important |

#### Images

* Images belong in source/img/ directory.
* Explain the image in written form.
* Title each image, this will create a URL for the image and enables linking to it.
* Always include a descriptive alt tag for accessibility.
* [Do not rely on everyone seeing colors the same way](https://en.wikipedia.org/wiki/Color_blindness).
* Prefer scalable vector images.
* When referring to images in markdown, use path from root, see example below

**Syntax example.** The quoted text is the alt tag and in parentheses is path to file

!["image of visual studio IDE"](./img/vs\_ide.jpg)

A { width=80% } attribute at the end of this string could help in resizing the image, but unfortunately it is processed poorly by quartz (this is reported at <https://github.com/princomp/princomp.github.io/issues/79>).

##### Images generated by LaTeX

Some images are generated by LaTeX: the .tex file is what is used to generate the .pdf file, and then pdf2svg converts the .pdf into a .svg file. pdftoppm furthermore convert the .pdf into a .png. `{=html} The.svgfiles are used in the.html,.odtand.docxdocuments, while the.pdfis used in the.pdf` documents. The resulting images are added to the repository so that there is no need to re-compile them every time, or to set-up LaTeX and latexmk on each system.

#### Diagrams

The diagrams are created using [Mermaid](https://mermaid.js.org/) and located in source/diag. Note that because of [an annoying bug](https://github.com/mermaid-js/mermaid-cli/issues/730) present on github’s server, mermaid-cli [must call pupeeter with the --no-sandbox](https://github.com/mermaid-js/mermaid-cli/blob/340561040b6b0621a486e3fc96723139e5718268/docs/linux-sandbox-issue.md) option, which constitutes a potential safety issue.

##### Class Diagrams

The *class* UML diagrams are created using [Mermaid](https://mermaid.js.org/) and located in source/diag/cla.

To create a new class diagram, say for a Documentation class, follow those steps:

1. Create a Documentation.txt file in source/diag/cla that follows [the syntax for class diagrams](https://mermaid.js.org/syntax/classDiagram.html) (note that there is no need to add classDiagram at the beginning, it will be done automatically),
2. Run (from the source/ folder) make diag/cla/Documentation.md,
3. Integrate the resulting drawing, properly captioned and with links to Documentation.txt, Documentation.svg and Documentation.png files using !include diag/cla/Documentation.md.

##### Flowchart Diagrams

The *flowchart* diagrams are created using [Mermaid](https://mermaid.js.org/) and located in source/diag/flo.

To create a new class diagram, say for a Documentation class, follow those steps:

1. Create a Documentation.txt file in source/diag/flo that follows [the syntax for flowchart diagrams](https://mermaid.js.org/syntax/flowchart.html) (note that there is no need to add flowchart at the beginning, it will be done automatically),
2. Add on the first line a comment %% title with “title” the title of the diagram,
3. Run (from the source/ folder) make diag/flo/Documentation.md,
4. Integrate the resulting drawing, properly captioned and with links to Documentation.txt, Documentation.svg and Documentation.png files using !include diag/flo/Documentation.md.

#### Source code

* Source code programs belong in source/code/ directory.
* The code included in this directory should either be:
  + Placed in the snippets/ sub-folder, and be a complete program.
  + Placed in the projects/<solution>/<project>/ sub-folder, and contains a Program.cs file:
    - Go to source/code/projets/,
    - Create a subdirectory with the name of the solution you would like to use,
    - Create a subdirectory with the name of the project you would like to use,
    - Create a file called Program.cs in
  + source/code/projects/<solution>/<project>/Program.cs
    - If you want to add additional classes, add them in code/projects/<solution>/<project>/<Class>.cs files.
  + Do **not** add solution (sln) or project (csproj) files: they will be created automatically using the project and solution’s name you specified (and a makefile rule [similar to this one](https://github.com/csci-1301/C-Sharp-project-maker)), if multiple classes are present they will all be linked, and the resulting archive will be hosted at content/code/projects/<solution>.zip.
* Source code that is faulty, partial, or does not terminate can be included in markdown as inline code block. ``{=html}

Code snippets can be included in markdown documents using [pandoc-include](https://github.com/DCsunset/pandoc-include) filter:

```text  
 !include code/sample.cs  
 ```

Note that for [an unknown reason](https://github.com/DCsunset/pandoc-include/issues/45), no special characters (such as \_) should be used in the filenames.

* If a “download” attribute is given to the code block, then a download link will be added, pointing to its value, by the add-links-to-projects.lua filter:
* string filePath = Path.Combine(  
   AppDomain.CurrentDomain.BaseDirectory,  
   "RandomNumbers.txt"  
   );  
   Random gen = new Random();  
   try  
   {  
   StreamWriter sw = new StreamWriter(filePath);  
   for (int i = 1; i <= 100; i++)  
   sw.WriteLine(gen.Next(1000));  
   sw.Close();  
   }  
   catch (Exception e)  
   {  
   Console.WriteLine("Exception: " + e.Message);  
   }
* [*(Download this code)*](https:/princomp.github.io/code/projects/FileRandomNumber.zip)
* will include a link to ./code/projects/FileRandomNumber.zip below the code block.
* Title each source code block included in markdown, this will create a URL for the code block and enables linking to it.
* code blocks are by default annotated as csharp
  + syntax highlighting is applied automatically at build time based on the code block language
  + to use a language other than C#, specify the language locally in the specific code block:
* only include code in text form such that it can be copy-pasted for reuse
* make sure to include blank lines before and after code blocks, since the absence of these can cause the code block to display incorrectly.

##### Tidying Source code

[CSharpier](https://csharpier.com/) is used to tidy the source code and make it uniform. Use

make tidy

to tidy all the source code present in the source/code/ folders. The [configuration file](https://csharpier.com/docs/Configuration) is at source/code/csharpierrc.yaml.

### Creating new lectures

Lecture notes belong to the source/lectures/ directory.

To create a new lecture, for instance on exception handling:

1. Create a directory corresponding to the theme if it does not exist already (say, exceptions), under source/lectures/ directory
   * Follow the existing pattern for naming convention which is lowercase and separation by underscores.
   * At the root of this folder, create an index.md file (so, at source/lectures/exceptions/index.md) containing
   * ---  
     title: Desired Title for Theme  
     ---
   * so that your theme will be labeled “Desired Title for Theme” on the website’s menu (see [content labelling](#content-labelling) on how to further label it).
2. Under the directory corresponding to your theme, create a file named after the lecture’s title (e.g., exception-handling.md) in lowercase. Write lecture notes in this file [using markdown](#markdown).
3. Edit the source/order file and insert where appropriate
   * ./lectures/exception/ (if you created a folder called exception),
   * ./lectures/exception/exception-handling.md (which *must be* between ./lectures/exception/ and the next ./lectures/xyz/ folder).

* This last step will insure that your lecture is 1. included in the book, 2. sorted correctly on the website’s menu (the default ordering is alphabetical).
* The order file, unfortunately, does not accept the same folder name twice (even if they are located in different folders or at different levels): there is no good solution to [this problem](https://github.com/princomp/princomp.github.io/issues/46), one has simply to make sure that no two folders have the same name.

If the lecture does not appear, here are the steps for troubleshooting the issue:

1. Check that after committing changes, the automated build has completed successfully, by checking [the workflows](https://github.com/princomp/princomp.github.io/actions),
2. The newly created lecture is under the subdirectory you picked in the [source/lectures/ directory](https://github.com/princomp/princomp.github.io/tree/main/source/lectures),
3. The .md file exists,
4. Hard refresh the browser page if viewing the resources website

**Known issues**: When concatenating files pandoc may or may not include empty spaces between individual files. This may cause the subsequent lecture title to not appear in the generated book. For this reason, each lecture file should end with a newline.

### Creating new labs

The process is very close to [the process to create a new lecture](#creating-new-lectures), with the following exceptions:

* All lab resources are located under source/labs/ directory, at root level (there is no “theme” sub-folder).
* You do not need to edit the source/order file, since labs are not included in the book nor sorted on the website.

Additionally, remember to:

1. Choose a short and unique name that describes the lab (say, StringMethods.md)
   * follow the existing convention for naming,
   * do not number labs or make assumptions about numbering because another instructor may not follow the exact same lab order,
   * make the lab standalone to support alternative ordering (avoid assumptions about what was done “last time”),
   * do not make assumptions about student using specific OS, include instructions for all supported options (Windows, MacOS, Linux),
   * do not make assumptions about student using Visual Studio, refer to IDE instead.
2. (optional) You can add a downloadable project (use a link of the form [the Rectangle project](./code/projects/Rectangle.zip)) or include snippets of code by following [our instructions to add source code](#source-code).

Using this established build system generates labs that are cross-platform (Windows, MacOS, Linux) and work on different IDEs (this process is documented [in the corresponding repository](https://github.com/csci-1301/C-Sharp-project-maker)). Do not attempt to create labs locally as that approach does not have the same cross-platform guarantee.

### Content Labelling

#### Technically

[Quartz](https://quartz.jzhao.xyz/authoring-content#syntax) support a powerful [tagging system](https://quartz.jzhao.xyz/features/folder-and-tag-listings#tag-listings) which should be leveraged. Markdown files can contain at their very top a [YAML metadata block](https://pandoc.org/MANUAL.html#extension-yaml_metadata_block) containing, e.g.

---  
tags:  
- Resource  
---

to “tag” this resource with “Resource” so that it will appears in the [tag listing](https://princomp.github.io/tags/Guide). To include multiple tags, simply make a list:

---  
tags:  
- Resource  
- Guide  
---

#### Conceptually

We will follow the guidance provided [on this page](https://karl-voit.at/2022/01/29/How-to-Use-Tags/):

* Use as Few Tags as Possible
* Limit Yourself to a Self-Defined Set of Tags
* Tags Within Your Set Must Not Overlap
* By Convention, Tags Are in Plural
* Tags Lower Case
* Tags Are Single Words
* Keep Tags on a General Level
* Omit Tags That Are Obvious
* Use One Tag Language
* Explain Your Tags

## Styling and Templating

Templating files are under source/templates/ directory. Templates directory contain layout files that are applied by pandoc when resources are built: note that [the website’s style](#editing-the-website) uses a completely different mechanism.

For maintainability reasons it is preferable to apply templates during build time. This strategy makes it easy to edit templates later and apply those changes across all resources. Avoid applying templating to individual resource files whenever possible.

Currently templates directory contains the following:

* docx/ - contains template used to produce .docx files (this template is not used yet, for [size issues](https://github.com/csci-1301/csci-1301.github.io/issues/156)).
* filters/ - contains pandoc filters for annotating code blocks, configured to default to C#, which then allows applying syntax highlighting to all code block.
* html/ - contains template used to produce *only the book.html file* (to edit the style of the website, refer to [editing website](#editing-the-website))
* latex - contains templates used to produce .pdf files,
* docx/ - contains template used to produce .odt files.

### Updating docx template

*Note that this template is not used yet, for (among other)* [*size issues*](https://github.com/csci-1301/csci-1301.github.io/issues/156)*.*

To edit this template, start by obtaining the default template file:

pandoc -o custom-reference.docx --print-default-data-file reference.docx

Then, open reference.docx, and, following loosely [this tutorial](https://support.microsoft.com/en-us/office/customize-or-create-new-styles-d38d6e47-f6fc-48eb-a607-1eb120dec563?ui=en-us&rs=en-us&ad=us), do:

* Click pretty much anywhere, and right-click on the highlighted style (displayed if you are under “Home”, you may need to scroll down the styles),
* Change the font for everything but the source code,
* Click on the “Block code”, then right-click on the highlighted style, and select the font for the source code,
* The font for “Verbatim Char” was also changed, but I am not sure if this has an impact,
* [Make sure the fonts are embedded](https://support.microsoft.com/en-us/office/benefits-of-embedding-custom-fonts-cb3982aa-ea76-4323-b008-86670f222dbc),
* Save and close the document.

This was inspired by [this post](https://stackoverflow.com/a/70513063) but does not seem to work properly.

### Updating odt template

First, output the default template file:

pandoc -o custom-reference.odt --print-default-data-file reference.odt

Then, open reference.odt, and, following loosely [this tutorial](https://github.com/jgm/pandoc/wiki/Defining-custom-DOCX-styles-in-LibreOffice-(and-Word)#libreoffice), do:

* Click on View, then Styles.
* Right-click on “Preformatted Text”, click on “Modify…”, and then select the desired font family for source code.
* In the dialog or sidebar which opens make sure the button in the top panel marked with ¶ is highlighted (it is very subtle).
* In the menu at the bottom of the dialog/sidebar choose Applied Styles. Only “Default Paragraph Style” and “Footer” should appear.
* Right-click on “Default Paragraph Style”, click on “Modify…”, and then select the desired font family for the rest of the text.
* Then, highlight the A next to ¶.
* Right-click on “Source\_Text”, click on “Modify…”, and then select the desired font family for source code.
* Click on File, then Properties, then on the Font tab, click on “Embed fonts in the document”.
* Save and close the document.

## Building locally

It is generally not necessary to build this resource locally unless the intent is to preview templating changes or to make changes to build scripts. For the purposes of editing content, it is sufficient to make edits to markdown files and commit those changes.

#### Installing dependencies

To find the current list of dependencies needed to build this resource, refer to the [build and deploy script install section](https://github.com/princomp/princomp.github.io/blob/main/.github/workflows/build_and_deploy.yaml). The exact installation steps vary depending on your local operating system.

In general the following dependencies are needed:

* [pandoc](https://pandoc.org/installing.html)
* [texlive](https://www.tug.org/texlive/)
* [make](https://www.gnu.org/software/make/) and other standard unix utilities (such as sed or wget, all included in the [Windows Subsystem for Linux](https://learn.microsoft.com/en-us/windows/wsl/install)),
* [python 3.+](https://www.python.org/)
* packages and filters: [Pygments](https://pygments.org/download/), [pandoc-include](https://github.com/DCsunset/pandoc-include#installation), [texlive-xetex](https://tug.org/xetex/), texlive-latex-extra, lmodern, [librsvg2-bin](https://askubuntu.com/a/31446)
* symbola font

For this later, note that starting [with version 11](http://web.archive.org/web/20181228102842/http://users.teilar.gr/%7Eg1951d/Symbola.pdf), the licence is too restrictive for non-personal use. As a consequence, users are asked to make sure they do not use a version greater than v.10.24, which is “free for any use” and [archived on-line](http://web.archive.org/web/20180307012615/http://users.teilar.gr/~g1951d/Symbola.zip) (curious users can also refer to [the related webpage](http://web.archive.org/web/20180307012615/http://users.teilar.gr/~g1951d/)). Note that installing this dependency using a unix-like package manager will result in installing a version of the font that [is free to use in any context](https://metadata.ftp-master.debian.org/changelogs//main/t/ttf-ancient-fonts/ttf-ancient-fonts_2.60-1.1_copyright).

You can make sure you are currently using the latest version of panflute by running

pip install -U panflute

This is needed if running a recent version of pandoc (as of pandoc 3.1.6.1 at least).

#### Running the build

| ⚠ Warning |
| --- |
| Running make all can be *very resource-incentive* and may render your system unstable. Read this section entirely before running any command. |

#### Testing the installation

After installing all dependencies, from the source/ folder, run:

make

to display a list of useful rules.

It is recommended to first run a command building simple documents or copying files to test your installation, such as

make ../content/docs/about/credits.md  
make ../content/docs/about/credits.pdf  
make ../content/docs/about/credits.odt  
make ../content/docs/about/credits.docx  
make ../content/code/projects/Rectangle.zip  
make ../content/web-order.ts  
make ../content/img/create\_project\_monodevelop.png  
make ../content/fonts/hack/hack-italic-subset.woff

If this was successful, you can compile the [resources needed for the website](#website) using

make build-light

#### Building all resources

You can run

make -l 2.5 -j$(nproc --ignore=2) all

to create and populate the content/ folder at root level with all the resources compiled. Note that this command limits the number of jobs in parallel and the number of CPU used ([using this trick](https://stackoverflow.com/a/56607839)), but that [tweaking those values](https://stackoverflow.com/a/32487943) may be needed to find the sweet spot on your own machine.

If you want to speed-up the compilation time, you can run

make fetch

which will fetch the [latest build output](#build-outputs), extract it and populate the content/ folder using its content. Due to [make’s unique feature](https://makefiletutorial.com/) only the files whose source was edited will be re-created when executing make all the next time, hence saving *a lot* of time. However, please not that files moved or deleted will still be present in the build.

#### Debugging error messages

Debugging the errors returned by makefile can be tricky at times, but you can save the messages returned in a log.txt file using e.g.,

make -l 2.5 -j$(nproc --ignore=2) all > log.txt 2>&1

## Website

### Editing the website

The website <https://princomp.github.io/> is built from the .md files contained in the content/ folder using [a dedicated branch](https://github.com/princomp/princomp.github.io/tree/quartz) of [quartz](https://quartz.jzhao.xyz/). To edit the layout, style, or other features such as the footer, please *start by checking out the quartz branch* (using git checkout quartz), and then

* Refer to quartz’s [website](https://quartz.jzhao.xyz/), [repository](https://github.com/jackyzha0/quartz) and general community,
* Knowing that [multiple edits](#generate-the-git-patch) already tweaked its style.

A couple of indications about the edits made to quartz:

* The favicon at quartz/static/, and have been generated using <https://realfavicongenerator.net/>.
* The order in the menu is constructed using the content/web-order.ts file, itself generated from the source/order file in the main branch: refer to the makefile (again, in the main branch) for explanations on how this file is created, to [the quartz documentation](https://quartz.jzhao.xyz/features/explorer#use-sort-with-pre-defined-sort-order) for the main inspiration, and to the quartz.layout.ts and sortFn.ts files for the concrete implementation. Some folders are omitted thanks to the const omit in the quartz/components/Explorer.tsx file. If you change the order, setting

useSavedState: true, // To debug the explorer, change to "false" (this way, the menu is not cached / permanent),

to false in the quartz/components/Explorer.tsx file *may* help in refreshing the menu more easily.

* Other files edited or created include:
  + The files
  + quartz/components/AlternativeFormats.tsx  
    quartz/components/styles/alternativeFormats.scss
  + list alternative formats at the top of the page,
  + The files
  + quartz/components/Comments.tsx  
    quartz/components/scripts/darkmode.inline.ts  
    quartz/components/Footer.tsx  
    quartz/components/styles/listPage.scss
  + customize the footer and add a link to [our repository feedback](#maintaining-repository-feedback) (while following [the selected style](https://github.com/jackyzha0/quartz/issues/1161)),
  + quartz/styles/base.scss loads a different set of fonts,
  + The files
  + quartz/components/Explorer.tsx  
    quartz.layout.ts
  + tweak the menu and layout,
  + quartz.config.ts sets meta-data about the website,
  + quartz/components/pages/404.tsx customizes the 404 error message,
  + quartz/plugins/emitters/assets.ts emits the .md files (they are not available by default),
  + quartz/components/index.ts ties it all together.

Refer to [Generate the git patch](#generate-the-git-patch) for instruction on how to generate a patch containing all the edits performed to our local copy of quartz.

### Deploying locally the website

Follow closely those steps:

* [Build the resource locally](#building-locally) (note that running make build-light is enough to deploy the website).
* Move to the quartz branch by running
* git checkout quartz
* Note that the content/ folder is still here, but that the source is absent from this branch: only files related to quartz are committed in this branch.
* Rename the content/index.md file (this is due to [an annoying bug](https://github.com/jackyzha0/quartz/issues/1175)) by running

mv content/index.md content/index\_b.md

* Follow [quartz’s instructions](https://quartz.jzhao.xyz/#-get-started):
  + If you don’t have at least Node v18.14 and npm v9.3.1, install [node](https://nodejs.org/en/download/package-manager) and [npm](https://github.com/npm/cli?tab=readme-ov-file#installation) (npm is probably installed automatically when you install node),
  + Run the following commands *at root level* (do *not* enter the quartz/ folder):
* npm i  
  npx quartz create
* for this last command, select
* │ ● Empty Quartz
* then,
* │ ● Treat links as shortest path ((default))
  + If the previous command succeeded, run
* mv content/index\_b.md content/index.md
* to restore our index file, then
* npx quartz build --serve
* to start the server. Then, navigate to localhost:8080/ to see the website deployed locally.

### Updating quartz

Our local copy of quartz, [in the quartz branch](https://github.com/princomp/princomp.github.io/tree/quartz), is “frozen” in the sense that it corresponds to the development of quartz at a point of time. It is possible to

1. Save the edits made to our local copy (as a [git patch](https://git-scm.com/docs/git-apply)),
2. Pull the current version of quartz in a different branch (called quartz-update),
3. Apply our edits to this updated version of quartz,
4. Replace the quartz branch with the quartz-update branch to deploy the updated version of quartz with our edits.

This process is not without risks and requires to be able to [deploy locally the website](#deploying-locally-the-website) to test it before deploying it. The following guide was inspired [by this discussion](https://github.com/jackyzha0/quartz/issues/1145).

#### Generate the git patch

The first step is to save as a git patch all the edits that have been made on our local copy of quartz since it was last updated.

* Make sure you are
  1. At root level in your repository’s copy,
  2. In the quartz branch,
  3. That your branch is up-to-date.
* by running a command such as
* pwd && git checkout quartz && git pull
* Locate the commit (short) id of the last commit performed by quartz maintainer. A way of achieving this is to look for “PCP” in the commit messages, using
* git rev-parse --short :/PCP
* and then to look for the commit id of the commit that came *before* it. For instance, if the previous command returns 847e3356, then the command
* git rev-parse --short 847e3356^1
* will return information about the commit that came before that last commit: we will assume its (short) id is 3b74453f in the following.
* Visual inspection using [github’s interface](https://github.com/princomp/princomp.github.io/commits/quartz/) or a program such as [gitk](https://git-scm.com/docs/gitk) can facilitate this process. Note that removing the --short option will give the *long* version of the id, which may be harder to compare.
* Use the (short) id previously obtained to generate a patch containing all the changes made since that commit:
* git diff-index 3b74453f --binary > pcp\_quartz\_patch
* The --binary option insures that any file created will be included in the patch: as a result, this file can be heavy.
* Make sure this pcp\_quartz\_patch file is located at the root level in your repository’s copy but do not commit it to the repository.

#### Clone the latest version of quartz

Execute the following commands:

git remote add quartz https://github.com/jackyzha0/quartz.git  
git fetch quartz  
git checkout -b quartz-update quartz/v4

where quartz-update is the name we use for our branch, and quartz/v4 is the name of the branch in the quartz repository we want to copy.

#### Apply the git patch

There are two ways of applying the patch. First, make sure you are in the quartz-update branch by executing

git rev-parse --abbrev-ref HEAD

Then follows the first method if possible.

##### Using apply

First, check if the pcp\_quartz\_patch patch is applicable, by executing

git apply --ignore-space-change --ignore-whitespace --check --reject pcp\_quartz\_patch

Some sections of the patch may be rejected: make sure you take note of which file will need to be merged by hand. Then, apply the patch, using

git apply --ignore-space-change --ignore-whitespace --reject pcp\_quartz\_patch

Then look for the .rej files: they will contain the edited version of a file that you will need to merge manually with the updated version of the same file from quartz’s update.

##### Using patch

If git apply gave an error starting with

Checking patch quartz.layout.ts...  
error: while searching for:

then, instead, do

patch -p1 < pcp\_quartz\_patch

And look for the .rej files as described above. Note that using this technique *requires to copy the binary files by hand*. Indeed, you should receive warning messages like

File quartz/static/android-chrome-192x192.png: git binary diffs are not supported.

and those files will have to be copied by hand from another branch, and / or re-added to the repository.

##### Testing

Once you are done manually merging, **test** your updated version by [deploying locally the website](#deploying-locally-the-website) and making sure that quartz does not return any error. If everything looks ok, add all the new files and commit the edits using a message containing the “PCP” string (to facilitate future [generation of git patch](#generate-the-git-patch)), and push, using for example:

* First, use bash git add --all -n . to list all the files you are about to add: make sure you are not adding files from the content/ folder, for instance. If everything looks fine, proceed to the next step.
* Then, actually add the files, commit, and push, using:
* git add --all  
  git commit -a -m "Applying previous PCP patch."  
  git push origin quartz-update

#### Update the branch

**If you were able to fix all the conflicts and to check that the website could still be deployed locally**, then overwrite the quartz branch with the quartz-update branch, [by executing](https://www.reddit.com/r/git/comments/bqx85v/comment/eo8j4zh):

# Make sure your working tree is in a clean state  
git status  
  
# Check out the branch you want to change, e.g. some-branch  
git checkout quartz  
  
# Reset that branch to some other branch/commit, e.g. target-branch  
git reset --hard quartz-update

**If the deployment was successful and everything seems to be working**, you can delete the quartz-update branch, locally then remotely, by executing

git branch -D quartz-update  
git push -d origin quartz-update

## Repository Maintenance

This repository uses following tools and technologies:

* git - version control
* Github - to make source code available on the web
* markdown, LaTeX - for writing the resources
* pandoc - for converting documents to various output formats
* make - for specifying how to build this resource
* github actions - to automatically build the resource
* github pages - to serve the accompanying website
* additional packages for specific tasks: texlive, Pygments, pandoc filters, [lua filter](https://github.com/jgm/pandoc/issues/2104), etc.
* fonts-symbola - to produce the emoji and other symbols in the pdf document.
* [utteranc.es](https://utteranc.es/) - for feedback through website
* [csharpier](https://github.com/belav/csharpier) - to tidy the C# source code

### Build outputs

The resource material is organized into specific directories inside the source/ folder. These resources are then compiled into templated documents in various formats using [pandoc](https://pandoc.org/MANUAL.html). The makefile explains the exact steps applied to each type of resource.

### Github actions

This resource is built automatically every time changes concerning files in the source/ folder are committed to the main branch of the repository. This is configured to run on [Github actions](https://github.com/features/actions). The [workflow](https://github.com/princomp/princomp.github.io/blob/main/.github/workflows/build_and_deploy.yaml) that is automatically triggered has two jobs: one to build the resource, and one to deploy it.

Currently Github actions offers unlimited free build minutes for public repositories (and 2000 min/mo. for *private* repositories, should we ever need them), which hopefully continues in perpetuity (if it does not there are other alternative services). Going with one specific CI service over another is simply a matter of preference.

Following a successful build, the build script will automatically deploy the generated resources to an accompanying website hosted on [github pages](https://pages.github.com/).

#### Fetch and No Fetch Versions

There is a [second workflow](https://github.com/princomp/princomp.github.io/blob/main/.github/workflows/build_and_deploy_no_fetch.yaml) that is identical to the first one with one important exception: to speed up compilation, build\_and\_deploy.yaml uses make fetch to [speed up compilation time](#building-all-resources) by re-downloading the latest build output, and then compiling only the required files. This can sometimes complicate the propagation of changes, typically if a template is modified (as this does not triggers a re-compilation of the files using it currently) or if a file is renamed (as the previous version will not be deleted).

The [build\_and\_deploy\_no\_fetch.yaml](https://github.com/princomp/princomp.github.io/blob/main/.github/workflows/build_and_deploy_no_fetch.yaml) can be [triggered manually](https://github.com/princomp/princomp.github.io/actions/workflows/build_and_deploy_no_fetch.yaml) to force a “fresh” remote compilation.

### Creating releases

Currently a github action is setup to do the following: whenever a new commit is made to the main branch, the action will build the resource and add the generated resources as a [pre-release](https://github.com/princomp/princomp.github.io/releases) and tag them as [“latest”](https://github.com/princomp/princomp.github.io/releases/tag/latest). If a subsequent commit occurs it will overwrite the previous latest files and become the new latest version. This cycle continues until maintainers are ready to make a versioned release (or “package”).

Making a versioned release is done as follows:

1. Go to [repository releases](https://github.com/princomp/princomp.github.io/releases)
2. Choose latest, which contains the files of the latest build
3. Edit this release, giving it a semantic name and a version, such as v1.0.0. Name and version can be the same. (cf. [semantic versioning](https://semver.org/))
4. Enter release notes to explain what changed since last release
5. Uncheck “This is a pre-release”
6. Check “Set as the latest release”
7. Update release

Following these steps will generate a new, versioned release. The versioned releases will be manually uploaded to and archived on galileo.

Once this is done, remember to create the next pre-release:

1. Go to [the repository releases](https://github.com/princomp/princomp.github.io/releases).
2. Click on “Draft a new release”.
3. Pick the tag “Latest”.
4. Click on “Generate release notes”
5. Check “This is a pre-release”
6. Click on “Publish release”

### Maintaining repository feedback

Resource users can submit feedback about the resource through various means, one of which is leaving comments on the website. This feature is enabled by [utteranc.es](https://utteranc.es/), using repositories hosted by the [princomp github organization](https://github.com/princomp).

To manage user feedback over time, a semester-specific repository is created for issues only. This must be a public repository and located under the same organization as the resources repository. utteranc.es widget is configured to point to this repository. After a semester is over, this feedback repository will be archived, and a new one created for the next semester. This will simultaneously archive all older issues and reset the feedback across website pages.

#### Migrating feedback repository

The steps for migrating feedback target repository are as follows:

1. Create a new **public** repository under [princomp github organization](https://github.com/organizations/princomp/repositories/new). Follow the established naming convention (feedback-<fall|spring|summer>-<YYYY>), and leave all the options except for visibility (which needs to be set to public) by default.
2. Go to repository Issues (make sure issues is enabled in repository settings).
3. Create a new label whose *label name* is comment (to match widget configuration as indicated in quartz/components/Footer.tsx, in the quartz branch).
4. Go to [Organization Settings > Installed GitHub Apps](https://github.com/organizations/princomp/settings/installations).
5. Choose “utterances” > “configure”
6. Under “Repository access” > “Only select repositories”
   * Select the repository created in step 1.
   * Remove the previous semester feedback repository.
   * Save.
7. In princomp/princomp.github.io/ repository, [in the quartz branch](https://github.com/princomp/princomp.github.io/blob/quartz/quartz/components/Footer.tsx), open quartz/components/Footer.tsx
8. Update utteranc.es widget code to point to the new feedback repository created in step 1.

* <script data-external="1"  
   src="https://utteranc.es/client.js"  
   repo="princomp/{REPOSITORY\_NAME}"  
   label="comment" …>  
  </script>

1. Commit change to quartz/components/Footer.tsx
2. Make sure the feedback works after migration. If it does not, retrace your steps.
3. Archive the earlier feedback repository in its settings.

### Maintaining Instructors Rights

This is handled by the [csci-1301 github organization](https://github.com/csci-1301) and documented at <https://csci-1301.github.io/user_guide.html#maintaining-instructors-guca-rights>.

# How to get Help

| 🛈 Note |
| --- |
| This page is primarily targeted for Augusta University students. |

This page lists resources for Augusta University students to receive help with their course of studies, [in general](#in-general), for [students of the School of Computer and Cyber Sciences](#X141ad883720f20ad850ac7cee477830489ae153), and for [this course in particular](#for-this-course).

## In General

Many resources are available to help you be a successful student:

* If you are food insecure, [you are not alone](https://www.wjbf.com/csra-news/nearly-36-percent-of-college-students-are-hungry/), and the [Open Paws Food Pantry](https://www.augusta.edu/student-affairs/open-paws.php) will help you.
* For tutoring resources, consult the [Academic Success Center](https://www.augusta.edu/academicsuccess/) (or “ASC”). It can help you, among other things, in the areas of time management, test preparation and study strategies.
* [Student Counseling & Psychological Services](https://www.augusta.edu/counseling/) (or “SCAPS”) is here to assist students with a variety of personal, developmental, and mental health concerns.
* The [Writing Center](https://www.augusta.edu/cwe/) can help you with any written, oral, or multimedia project.
* To get help with technologies, refer to our [Instructional Technology Support](https://www.augusta.edu/continuity/index.php) correspondent [Sienna Sewell](https://spots.augusta.edu/sSewell/).
* The [Department of Multicultural Student Engagement (MSE)](https://www.augusta.edu/multicultural/) aims to provide education, training, and programming to foster awareness of diversity and inclusion among Augusta University students. Their [Multicultural Mentorship Program and African American Male Initiative](https://www.augusta.edu/multicultural/programming.php) are excellent resources to receive additional help.

## For Students of the School of Computer and Cyber Sciences

### School of Computer and Cyber Sciences Tutoring Center

The School has a tutoring center that can be reached:

* On [discord](https://discord.com/invite/AYSw3UNKEh),
* During their tutoring hours (hours posted on the door and on discord), in [University Hall](https://map.concept3d.com/?id=824#!m/268018) 129.

### ACM Club

The [Augusta University chapter](https://spots.augusta.edu/cyberdefense) of the [A.C.M](https://www.acm.org/) is one of the university’s best resources for Computer Science, Information Technology and Cyber Security students. It provides a platform to network with other students in similar majors, presenting countless opportunities to not only expand the people you know, but also a fantastic place to learn and ask questions. To learn more, you can sign up for the newsletter, or attend one of the subgroup meetings (meeting times and locations are listed [on the website](https://spots.augusta.edu/cyberdefense)).

### Other Club Activities

The Augusta University Game Design Club and Girls Who Code College Loop “will be continuing activities in full force this year”. Notifications for upcoming activities will be shared in class alongside school-wide emails.

## For This Course

### How to Ask a Question?

It may seems silly, but asking a question “the right way” may not always be easy.

1. Once you’ve identified your issue, try again from scratch to see if you missed a point.
2. Go over the instructions, and [look in our resources](https://github.com/princomp/princomp.github.io/search?q=ask+a+question) for some meaningful keywords.
3. Think about how you can describe your issue, what is the shortest route to reproduce it.
4. If you are still facing difficulties, be detailed and clear about what you think went wrong: if the question is related to computers, specify which operating system, what you have tried, the exact nature of the error message, etc. Screenshots are not always the right way to convey your question: try to be descriptive, and explain what you tried. If you want to refer to a particular lab or lecture, open the corresponding page, look for the closest title, hover over it, and you should see a “§” symbol appears: click on it, you can now [share that link](https://www.wikihow.com/Copy-and-Paste-a-Link) so that your interlocutor knows precisely what you are talking about!

And, remember: your instructor(s) knows that you are a student and here to learn, so you should *never* feel intimidated or assume that *everyone knows better than you*: many students struggle in this class at times, and you could actually do them all a favor by asking your instructor(s) to go over a particular dimension that they may have overlooked or explained poorly!

### Commenting Using a Github Account

On the website version of this resource, you can see at the bottom of every page a box where you can comment. This will require that you create a [Github account](https://github.com/login), which is free and may serve multiple purpose if you intend to study, use, or contribute to open-source projects. The comment can use the [markdown syntax](https://commonmark.org/) (exactly like this resource!), which is also used on websites like [stackoverflow](https://stackoverflow.com/editing-help) and extremely popular!

You are also welcome to [open an issue](https://github.com/princomp/princomp.github.io/issues/new/choose) on our website.

# Choosing Your Major

| 🛈 Note |
| --- |
| This page is primarily targeted for Augusta University students. |

## Which degree is best for you?

Most universities offer both a Computer Science degree and an Information Technology degree, and some universities even offer a Management Information Systems degree. [Here at Augusta Unversity](https://www.augusta.edu/ccs/programs.php), we have all three options for you:

* [Computer Science](https://www.augusta.edu/ccs/bs-cs.php) (CS / CSCI),
* [Information Technology](https://www.augusta.edu/ccs/bs-it.php) (IT / AIST),
* and [Cybersecurity](https://www.augusta.edu/ccs/bs-it-cybersecurity.php) (CYBR),

along with two unique diploma,

* [Cybersecurity Engineering](https://www.augusta.edu/ccs/bs-cybersecurity-engineering.php),
* and [Cyber Operations](https://www.augusta.edu/ccs/bs-cyber-ops.php).

While all of these degrees are high-quality and should place students on a fast-track towards a successful career, students always ask the same question, “*Which degree is best for me?*” The answer to this question depends on the student, their career goals, and a variety of other factors.

Students even ask more specific questions:

* Which degree will give me the highest salary?
* Which degree is easiest?
* Which degree is hardest?
* Which degree has the most job opportunities?

These are all great questions! But before answering them, it is more important to have a basic understanding of the degree options.

The following links detail these three degrees and explain the benefits of each:

* [Difference Between a Computer Science & Information Technology Degree](http://online.king.edu/information-technology/difference-between-a-computer-science-information-technology-degree/)
* [Computer Science vs Information Systems/Technology](https://www.geteducated.com/careers/521-computer-information-systems-vs-computer-science)
* [Degrees that Pay You Back (from Wall Street Journal)](http://online.wsj.com/public/resources/documents/info-Degrees_that_Pay_you_Back-sort.html)

Additionally, Augusta University has [more information on its advising page](https://www.augusta.edu/advising/). To answer the first question (“*Which degree will give me the highest salary?*”), you can use [Georgia Degrees Pay](https://www.usg.edu/georgia-degrees-pay)

## Summary

*Computer scientists* design and develop computer programs, software, and applications. *IT and IS professionals* then use, configure, and troubleshoot those programs, software, and applications.

So it really depends on what you want to do. Do you want to be on the front end, designing the software and applications? Do you prefer to use and troubleshoot them? One of the websites gave the analogy of a home: computer scientists build the home, set up home, install the lighting, plumbing, etc., and then the IT/IS professionals come and live in the home to use it, test it, and troubleshoot it.

### So which degree is “best”?

Perhaps you can now see how this question is not fair or at least not clear. If we ask which degree is more difficult, the students will immediately exclaim, “Computer Science is the most challenging!” Therefore, one can perhaps argue that the Computer Science degree is the most rigorous (challenging) and will likely provide the student with more opportunities in their career. And the salary statistics support this argument, as CS students, on average, have a higher salary than their IT and IS colleagues.

That said, is Computer Science better? Yes, and no. It depends on **you**! It depends on your goals. It depends on how hard you want to work. For some, “better” means more money and more career opportunities. For others, “better” means easier studies and less math! So again, which degree is “best”? There is no short answer. As mentioned above, all three degrees provide the tools you need to hopefully have a great career. Perhaps the question is best worded as, “Which Degree is Best for **me**?” And of course, only **you** can answer this question!

# Course Assistants

| 🛈 Note |
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| This page is primarily targeted for Augusta University students. |

## What Is an Undergraduate Course Assistant?

In this course, an Undergraduate Course Assistant (UCA) is generally present in addition to your instructor. A UCA is a student, generally in the School of Cyber and Computer Sciences, who successfully passed CSCI 1301 and that is hired by the School to assist other students.

Their duties generally include:

* Helping the students during the labs,
  + To set-up their computers,
  + To find the right resources,
  + To understand their IDE’s error messages,
  + To investigate bugs with them,
  + etc.
* Helping the students outside of the lab (through email, teams, or office hours), for similar tasks as in lab, but also to get ready for an exam or a quiz,
* Reporting to the instructors any issue, mistake or confusion they noticed,
* Suggesting improvements to the resources shared with the students.

Their duties *can not* include:

* Understanding for you[[1]](#footnote-1),
* Helping you or even commenting on graded material *before* it was graded,
* Grading students’ work,
* Helping you with other classes,
* Helping you becoming a self-regulated learner and work on your schedule[[2]](#footnote-2).

## How Do I Become One?

A UCA is hired by the School upon recommendation of instructors, after discussion with our Academic Program Coordinator, and possibly our Director of Undergraduate Studies.

A UCA *must*:

* Be a student, that is, currently enrolled in courses, or, if during the Summer, being enrolled in courses for the next Fall semester,
* Pass our Human Resources background check,
* Have an interest in tutoring,
* Clearly understand the limits and boundaries to the help they can provide to students.

Additionally, if a student wants to help with this particular class, then the student must have successfully passed CSCI 1301 with a grade of B or higher

A UCA will:

* Be able to work up to 25 hours per week (an average of 10 hours per week is typical, but needs to be discussed with the instructor), paid $12.50 per hour, without other benefits,
* Be adequately trained to use our platforms and edit our resources,
* Be able to work on Campus and discuss their schedule with their referent instructor,
* Develop a stronger bond with the instructors, facilitating possible future reference or research projects.

So, in short: talk to any CSCI 1301 instructor if you feel like becoming a UCA.

## I Am a UCA, What Should I Do Now?

Congratulations! You should now read more about your position in the [UCA starting guide](file:///C:\Users\NAFAHA\Downloads\M260-materials\uca_guide.html)!

## What Is the Difference With a GRA?

*Graduate* Course Assistants (GRA) hold a bachelor and are generally PhD or Master student. Their duties generally overlap with those of the instructors and those of the UCAs, as they are the first point of contact of UCAs, design projects, organize the schedule of the tutoring center and of the labs.

## What Is the Difference With a URA?

Undegraduate *Research* Assistants (or “URAs”) share many similarities with UCAs:

* They both are students employed by the University,
* They both have a maximum of 25 hours/week,
* Their pay rates are the same,
* They both work under the direction of a [Faculty member](https://www.augusta.edu/ccs/faculty.php).

However, their focus is on working on [*research*](https://www.augusta.edu/ccs/research.php) instead of being focused on teaching. The difference is sometimes tenuous, but URAs positions are generally given in priority to “advanced” students (that is, close to graduation), to use their gained knowledge to push further the limits of human knowledge!

It is not possible to cumulate an URA *and* an UCA position, but obtaining an UCA position is in general an excellent stepping stone to obtain a URA position, if you wish to do so: by proving that you are reliable, serious, agreeable to work with, you will maximize your chances of having a Faculty member notice you and offer you to work on their research with them.

# UCA starting guide

| 🛈 Note |
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| This page is primarily targeted for Augusta University students. |

Congratulations on your new position! This page briefly explain what is expected from you as an Undergraduate Course Assistant (UCA).

## The Three Rules

There are three important rules for you:

1. **This is a job.**

* Meaning that you have a contract that you should have read and understood, and that you need to carefully clock in and out to receive the pay you deserve. Briefly reviewing the information [listed here](https://www.augusta.edu/hr/university/university_benefits/studenthires.php), and in particular [those slides](https://www.augusta.edu/hr/university/university_benefits/documents/department_guide_studenthireprocess_fy_23.pdf) can help you in making sure that you understand all aspects of your position. Do not forget that you are first and foremost a *student*, and that your main goal here is to *graduate*.

1. **You are here to help students, not to solve their problems.**

* Please, review what you should and should not do [on this section](file:///C:\Users\NAFAHA\Downloads\M260-materials\ca.html#what-is-an-undergraduate-course-assistant). It is difficult to strike the right balance when helping a student, but a good rule of thumb is that you should not do anything yourself, just explain and give hints so that they can solve the problem they are facing. You are here to help students understand how to solve a problem, not to solve it for them.

1. **Don’t hesitate to ask.**

* That’s it. You are not alone to deal with difficult situations (cheating, rude behavior, student abusing your time, etc.), and it is normal if you are sometimes unsure of the best course of action. The instructors are happy to train you and help you solve problems that may arise.

In general, UCAs should prioritize giving clear and concise explanations and hints, as to avoid confusion while also helping them better understand the problem-solving process. This means that when you encounter a problem that you are not able to solve, it’s important to ask a colleague who is available for help and try to understand their approach. This way, the student can receive assistance more quickly and will be less likely to get confused during the troubleshooting process. By emphasizing the importance of understanding and working through the problem, rather than just providing a solution, tutors can help students develop the skills they need to become more independent problem-solvers.

On top of supporting students and helping the instructor, you are also encouraged to work on the improvement of those resources. Your contribution may range from spell-checking to pointing inconsistencies, from clarifying statements to re-organizing exercises. Thanks to git and [pull requests](https://github.com/princomp/princomp.github.io/pulls), you do not need to worry (too much) about introducing mistakes or blunders: the changes you suggest will always be reviewed by instructors before being merged in our master document. We discuss below how you can edit our resources.

## Editing the Resources

You need three things to start editing our resources:

* A github account & an invitation,
* Some working knowledge of markdown,
* Some working knowledge of github’s interface.

Follow the instructions in our [“Contributing Guidelines”](file:///C:\Users\NAFAHA\Downloads\M260-materials\contributing.html#if-you-are-a-uca) for the first step.

For a quick syntax guide in Markdown, the best resource is [this website](https://commonmark.org/help/) and its [10 minutes tutorial](https://commonmark.org/help/tutorial/). We list some [best practices](https:/princomp.github.io/docs/about/dev_guide#editing-resources), and would appreciate if you could follow them.

For github’s interface, please refer to the following guide.

“Navigating repositories”

The [ℙrinciples of ℂomputer ℙrogramming organization repository page on GitHub](https://github.com/orgs/princomp/repositories) contains many “repositories”:

* The [**princomp.github.io**](https://github.com/princomp/princomp.github.io) contains most of the resources that will be used (so it will be where you will navigate to the most),
* The **feedback-**<semester>**-YYYY** and similarly named repositories contain feedback submitted by students/users.

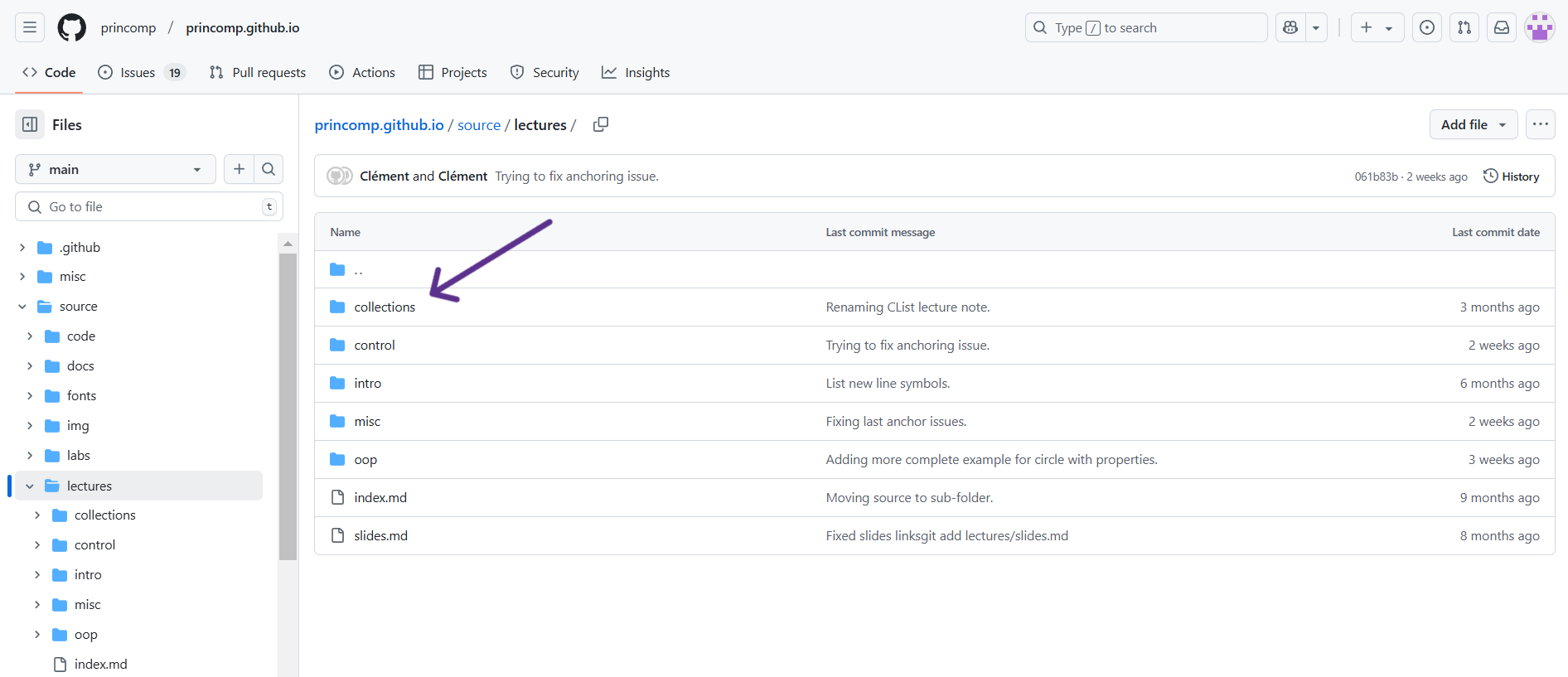
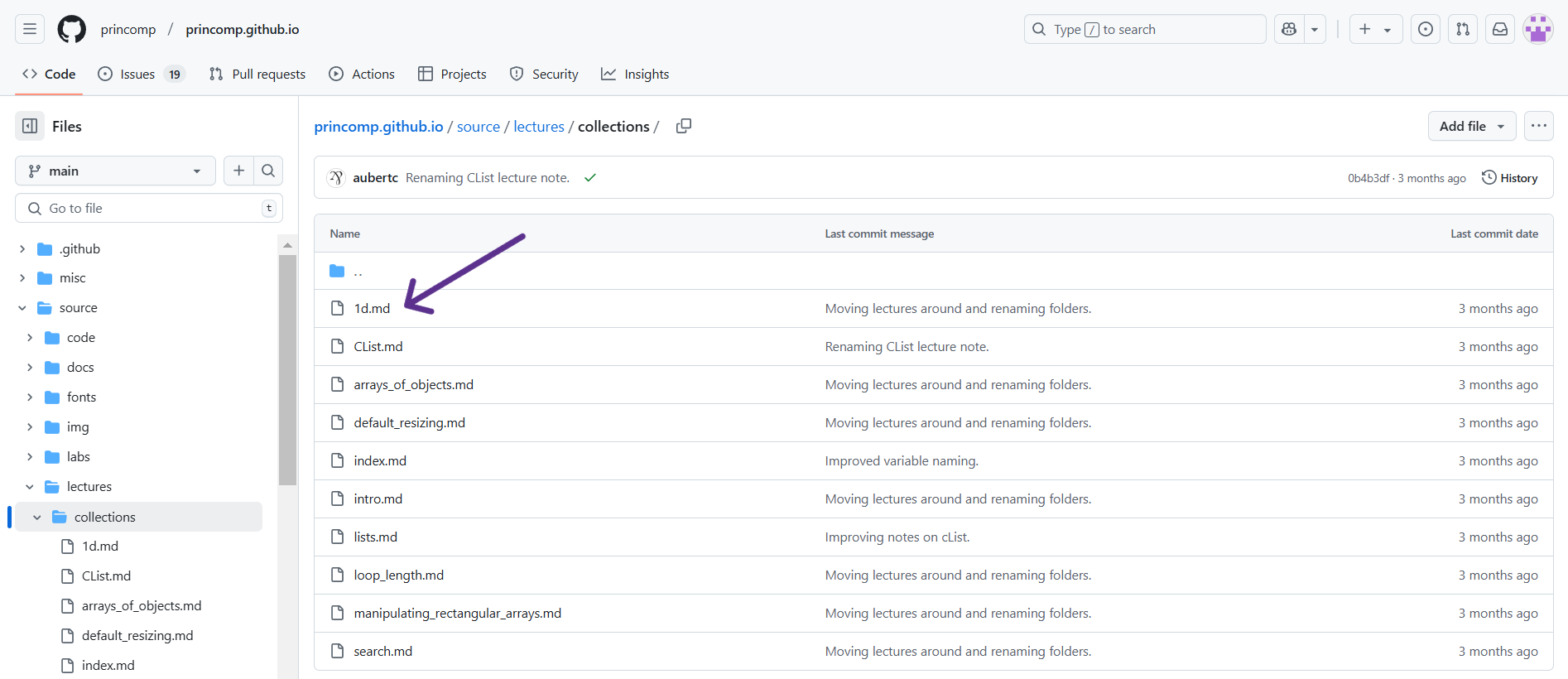
[Under the **Code** section](https://github.com/princomp/princomp.github.io/tree/main/) (next to Issues, Pull Requests, Actions, etc.), you will find various folders containing documents for the website.

“Navigating folders”

Typically, if there is some error or mistake, it will be under [source/lectures](https://github.com/princomp/princomp.github.io/tree/main/source/lectures), in the lecture notes, so that will be where you will navigate to the most:

Lecture Notes

The way the resources are organized [is explained here](https:/princomp.github.io/docs/about/dev_guide#resources-organization-overview).

For this example, I just clicked on the “Collections,” then “1d”.

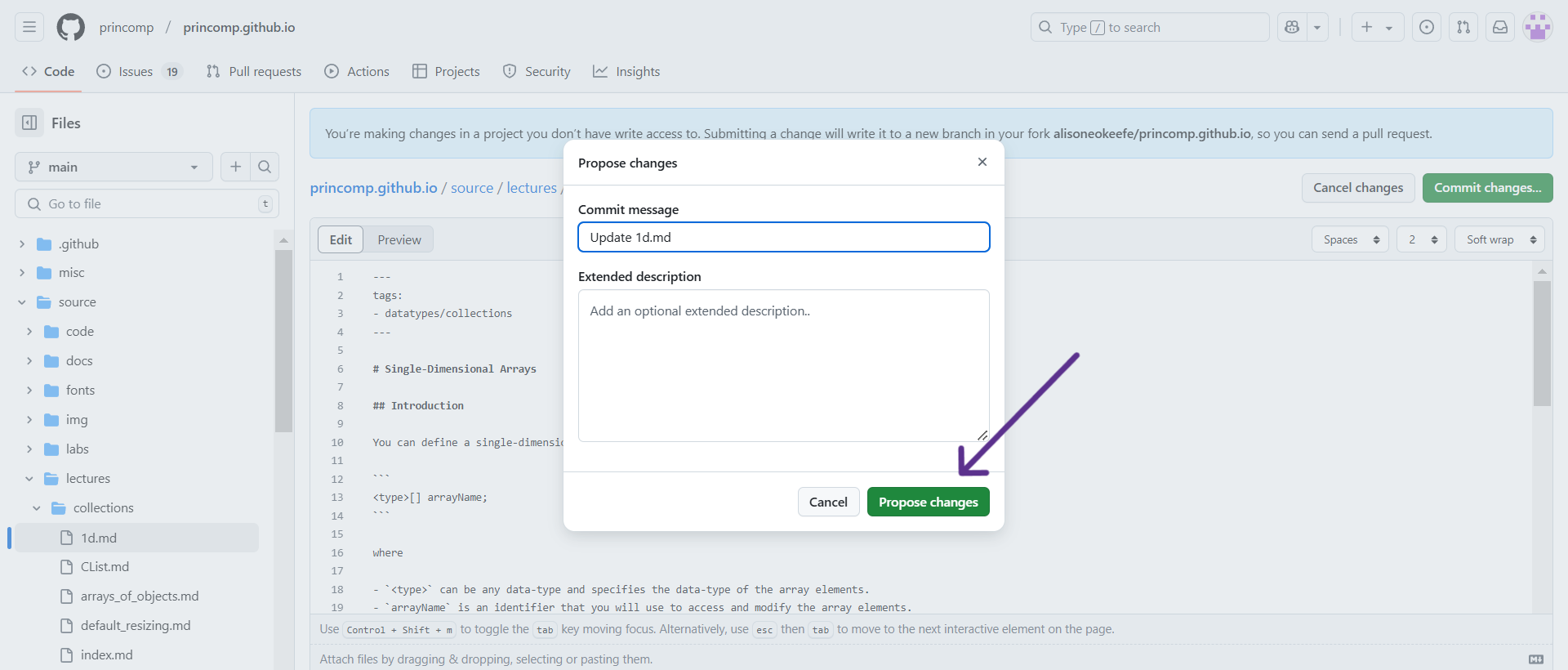
“Editing Mode”

On this page, you can see the edit history of that specific document you clicked on. In the corner above the document and below the edit history, there is a pencil icon that will put you into editing mode for that document.

When you click on the pencil icon, you will see the document formatted as markdown with two sections at the top of the document: *Edit file* and *Preview*. If you have *Edit file* selected, then you will see the “code” version of the document whereas if you click on the *Preview* button, you will see the document in its “final” form, or how the website users should see it, without the “code”. To edit, make sure you have *Edit file* selected.

“Committing Changes”

Once you have made the edits you wanted, you need to “commit” them; just like how you may write a paper, you need to submit it to the professor for them to see it. At the top right corner of the page, there is a button that says “Commit changes.” Then, a description box pops up for you to describe what you did so others will know the changes you made. (You do not need to go into *every* detail; just describe it generally, like “I fixed grammatical issues” or “Fixed code error.”)

 As a UCA, you do not have write access to the **princomp.github.io** repository, so submitting a change will write it to a new branch in your fork <your github handle>/princomp.github.io, so you can send a pull request. Given how Github works, after making the necessary edits, click the “Propose Changes” button located at the bottom. On this page and the next, there will be a “Create pull request” button. Clicking on this will start a pull request. After you have successfully created a new branch for your commit and started a pull request, your edits will be checked by others so as to catch any mistake(s) you may have introduced before your pull request is merged into the base branch.

“Committing”

### Uploading Images

Like the paragraph above states, UCAs don’t have write access to the **princomp.github.io** repository, which also means they are not able to add files to the img folder. If you find that you need to add image files, you still can, but you must upload them to your fork first. To access your fork, type github.com/<your github handle>/princomp.github.io in the address bar. The page that appears will look nearly the same as the one located at github.com/princomp/princomp.github.io. The folders and files will be organized the same way as well. Navigating to source/img will bring you to the correct folder. In the top right corner, directly above the edit history, there will be a button that says “Add file.” If you click this, two options appear: “Create new file” and “Upload files.”

If you click “Upload files,” you will be brought to a page where you’ll be able to drag files onto it or choose your files manually. When you’ve uploaded the files, select the radio button next to “Create a new branch for this commit and start a pull request.” Then, select “Commit changes” at the bottom of the page. You’ll then be prompted to submit a pull request. After this, you should be brought back to the main page of your fork. A yellow box will be at the top of the screen that says “branch name had recent pushes x minutes ago.” On the right of that box, there will be a button that says “Compare & pull request.” From here, you can submit a pull request as you would for any other commit!

# Computer Requirements

| 🛈 Note |
| --- |
| This page contains some recommendations on students wishing to buy a computer to complete their program in [the School of Cyber and Computer Sciences](https://www.augusta.edu/ccs/). Note that **possessing a computer** [**is not required to complete CSCI 1301**](https:/princomp.github.io/installing_software.md#accessing-an-ide), but recommended. |

## In Short

Anything less than 5 years old running [Microsoft Windows, macOs or a Linux operating system](#in-terms-of-operating-system) is probably fine. Second hand and custom built are fine, but you will in all likelihood needs a portable computer (as opposed to a desktop computer) to present your work and work on projects.

## In Terms of Hardware

### Desktop, Laptop, or something else?

A laptop is generally recommended (to take notes in class, make presentations, work on projects at School, …) but technically possessing only a desktop *should* be ok (and will be more comfortable to use, in all likeliness). Tablets and other “small” handled devices (such as [Netbooks](https://en.wikipedia.org/wiki/Netbook), [Chromebooks](https://en.wikipedia.org/wiki/Chromebook) or [Mini PCs](https://en.wikipedia.org/wiki/Mini_PC)) are **not** recommended and will in all likelihood prove challenging to use for some classes.

### Specifications

| Component | Minimum | Suggested | Comfortable |
| --- | --- | --- | --- |
| [CPU](https://en.wikipedia.org/wiki/Processor_(computing)) | 4 cores @ 2.66 GHz | 6 cores @ 3.8 GHz | 6 cores @ 4.4 GHz |
| [RAM](https://en.wikipedia.org/wiki/Random-access_memory) | 8GB | 16GB | 32GB |
| [Hard Drive](https://en.wikipedia.org/wiki/Hard_disk_drive) | 100GB | 500GB of [SSD](https://en.wikipedia.org/wiki/Solid-state_drive) | 1TB of [SSD](https://en.wikipedia.org/wiki/Solid-state_drive) |

[GPU](https://en.wikipedia.org/wiki/Graphics_processing_unit) and other special equipment are not required, but recent USB-C connectors will be useful.

#### As An Example

[Dr. Aubert](https://spots.augusta.edu/caubert/) uses a [Dell Latitude 5480/5488](https://www.dell.com/support/home/en-us/product-support/product/latitude-14-5480-laptop/docs) from **2017** (*but in no way endorses it*) with

* 4 cores @ 2.40 GHz CPU,
* 8GB of ram,
* 238 GB of hard drive,

and of courses wishes that it was a bit more responsive at times, but can conduct otherwise all his professional activities.

## In Terms of Operating System

We will briefly consider four “families” of operating systems:

* [Microsoft Windows](https://en.wikipedia.org/wiki/Microsoft_Windows) (Windows 10, Windows 11, etc.)
* [macOS](https://en.wikipedia.org/wiki/MacOS) (macOS Ventura, macOS Sonoma, etc.)
* [Linux operating systems](https://en.wikipedia.org/wiki/Linux) (Ubuntu, Debian, Gentoo, etc.)
* Operating systems that uses their web browsers as their principal user interface (essentially, [ChromeOS](https://en.wikipedia.org/wiki/ChromeOS)).

Note we do not discuss [Android](https://en.wikipedia.org/wiki/Android_(operating_system)) or [iOS](https://en.wikipedia.org/wiki/IOS) since they are primarily mobile operating systems, and not easily suited for the development workload in our curriculum.

### In Short

Anything but ChromeOS is (probably) fine.

### Expanded

* If you are (planning on) using [Visual Studio](https://visualstudio.microsoft.com/) as your IDE, then windows is your best choice of operating system.
* If you need to use macOS for whatever reason, then you will probably be able to accommodate all the requirements, but it may require some tweaking at times.
* Using Linux-based operating systems are a great way to learn how to tinker with your computer (you have full control!), but will sometimes require you to be creative to meet courses expectations.
* [Virtual machines](#virtual-machines) allow you to simulate (almost) any operating system using (almost) any operating system, and is required for some courses. Using virtual machines means, essentially, that your choice of operating system *does not matter at all*.
* Remember that [multi-boots](https://en.wikipedia.org/wiki/Multi-booting) (that is, installing multiple operating systems side-by-side) is an option.

### Virtual Machines

Virtual machines allow you to simulate (almost) any operating system using (almost) any operating system: this means that, for instance, you can load the Windows 11 operating system from your computer running Debian 12.5, or the Debian 12.5 operating system from macOS 14.

Note that CSCI 4532 - Hardware and Embedded Systems and CSCI 4531 - Malware Analysis and Reverse Engineering *require* you to run virtual machines. If you are planning on taking one of those classes, make sure your computer can run virtual machines!

You can find [on this page](https:/princomp.github.io/installing_software.md#installing-anything-anywhere) some indications on how to run a virtual machine on your computer, and you can check on-line the recommended specifications for [Hyper-V](https://learn.microsoft.com/en-us/virtualization/hyper-v-on-windows/reference/hyper-v-requirements), [VirtualBox](https://www.virtualbox.org/wiki/End-user_documentation), [kvm](https://www.linux-kvm.org/page/FAQ#What_do_I_need_to_use_KVM?), [vmware](https://www.vmware.com/products/workstation-player.html). Note that, as a student, you can obtain [a free licence for Windows](https://portal.azure.com/?Microsoft_Azure_Education_correlationId=696fbf50-4829-476c-bfc8-09974888f850#view/Microsoft_Azure_Education/EducationMenuBlade/~/software).

## Where to Buy?

That is really up to you, but remember that, as a student (or employee), you are allowed to

* [Some discounts](https://my.augusta.edu/discounts/electronics.php),
* [A free licence for Windows](https://portal.azure.com/?Microsoft_Azure_Education_correlationId=696fbf50-4829-476c-bfc8-09974888f850#view/Microsoft_Azure_Education/EducationMenuBlade/~/software).

Second-hand computers or even custom-built computers are probably fine, but requires more skills (such as how to factory-reset a computer and / or how to (re)install an operating system) and inspections on your end.

## Is There Anything Else I Should Know?

* A well taken-care of computer can easily last 5 years, but laptops are harder to upgrade and preserve in good shape than desktops.
* Ergonomics is important: you will most likely spend *many hours* on your computer, so make sure [your workstation is well organized](https://www.wikihow.com/Set-Up-an-Ergonomically-Correct-Workstation).
* A programmer is first and foremost a typist: make sure you develop good habits and [learn to type correctly](https://www.wikihow.com/Type). Exploring [ergonomics keyboard layouts](https://en.wikipedia.org/wiki/Keyboard_layout#Other_Latin-script_keyboard_layouts) and [ergonomics mice](https://en.wikipedia.org/wiki/Computer_mouse#Ergonomic_mice) can save you later from carpal tunnel syndrome, arthritis, and other repetitive strain injuries.

# Installing Software

## Generalities on Installing Software

You probably already installed software in your life, be it [VLC](http://www.videolan.org/), [Microsoft Teams](https://www.microsoft.com/en-us/microsoft-teams/download-app), or [Whatsapp](https://www.whatsapp.com/). However, depending on whether you installed it on a phone, a tablet, a computer, and depending on the operating systems (Android, Windows 10, iOS, Ubuntu, etc.) your experience may have varied drastically.

Between the [Play store](https://en.wikipedia.org/wiki/Google_Play#Play_Store_on_Android), the [command-line interface](https://en.wikipedia.org/wiki/Command-line_interface), [homebrew](https://brew.sh/) and the act of downloading software using your browser and then installing it using the navigator, there can be a lot of differences, but in all those circumstances you should keep security in mind. In addition to making sure that you are downloading the software from a trusted source, you should also be vigilant about the information the software will be able to access about e.g., your private life.

As data can be lost or corrupted upon downloading, many platforms now use [checksums](https://en.wikipedia.org/wiki/Checksum) to verify the integrity of the software you downloaded before installing it. This is an excellent practice that can also be performed “by hand”, as explained for instance for [the database manager MySQL](https://dev.mysql.com/doc/refman/8.0/en/verifying-package-integrity.html): the main idea is that the probability of the signature matching a tampered-with file is extremely low, and that as long as you are downloading the signature and the software from two different sources, you are considerably reducing the [attack surface](https://en.wikipedia.org/wiki/Attack_surface).

## Executing Code Found on-line

As you progress in this class, you will be asked more and more to download and execute code hosted [in our repository](https://github.com/princomp/princomp.github.io/). How can you tell that you can trust this code?

We have not implemented checksum-matching (yet!), but you can trust this code as it was coded by your instructors, and hosted on a platform using [two-factor authentication](https://docs.github.com/en/authentication/securing-your-account-with-two-factor-authentication-2fa/about-two-factor-authentication) where every action is tracked using [versioning](https://en.wikipedia.org/wiki/Software_versioning). Concretely, this means that only somebody who manages to steal your instructor’s credentials and their phone, and thwart all the other instructors’ vigilance, would be able to host malicious code on our platform: while we certainly imagine that this is theoretically possible, we hope that you will agree that the probability is low enough for you to trust the code on this site.

As often, security is not absolute, but aims at providing reasonable confidence. Executing “blindly” code found on-line, on the other hand, gives you a good chance of facing unpleasant surprises: while there certainly is a lot of useful, good code on websites like [stackoverflow](https://stackoverflow.com/)your instructor probably uses such websites, by the way!, copying-and-pasting it without understanding its purpose or general structure is almost guaranteed to, at best, not execute properly, at worst, make your system unstable or insecure.

## Accessing an IDE

An [IDE](https://en.wikipedia.org/wiki/Integrated_development_environment), for “Integrated development environment”, is the software or service you will be using to write, compile, execute and debug your code. There are many available IDEs, and some can accommodate multiple different programming languages.

For C#, [there are many different possibilities](https://en.wikipedia.org/wiki/Comparison_of_integrated_development_environments#C%23): some are cross-platforms (meaning you can use them on macOS, Windows or Linux), some are provided free of charge, some have not been updated in a long time. Three natural choices are [Visual Studio](https://visualstudio.microsoft.com/), [MonoDevelop](https://www.monodevelop.com/) and [Rider](https://www.jetbrains.com/rider/features/). While the last two are accessible on every operating systems, Visual Studio is available only for Windows, and in a slightly different version for macOS.

To access one or the other, you will need either

* a computer with the right to install software on it,
* to access one of the computers in the [computer lab](https://my.augusta.edu/it/computers-printing.php#walkinlabs), or
* a computer with internet access.

The third solution is a backup plan, as instead you will access a very minimal version of an IDE to test small snippets of code. You should not rely on it for the duration of this course.

### Installing an IDE On Your Own Computer

This part gathers some references for you to install [Visual Studio](https://visualstudio.microsoft.com/), [MonoDevelop](https://www.monodevelop.com/) and [Rider](https://www.jetbrains.com/rider/features/) on your own computer, regardless of your operating system. It is strongly encouraged that you do so, especially if you want to continue in a CS/IT/Cyber degree, but is not mandatory[[3]](#footnote-3).

The instructions are detailed, but there are plenty of ways this can go wrong: make sure you have read and followed those instructions carefully before [asking for help](https:/princomp.github.io/labs/Introduction#how-to-get-help)!

#### Installing Visual Studio On Your Own Computer

Note that we are *not* installing “Visual Studio *Code*”, but simply “Visual Studio”.

##### For Windows

1. Visit [Azure Dev Tools for Teaching](https://aka.ms/devtoolsforteaching).
2. Log in using your Augusta University credentials.
3. Select “Download software”.
4. Look for Visual Studio. The path is Education → Software → Visual Studio Enterprise 2019/2022. You can search “Services” for the “Education” group and then click “Software” if the education group is not immediately displayed. It should look like the following:

* How to find Visual studio in the list of Education Software
* Normally, the following direct link should get you to the right page: <https://portal.azure.com/?Microsoft_Azure_Education_correlationId=8ee63052-dc32-46f7-a109-e26793622dbf#view/Microsoft_Azure_Education/EducationMenuBlade/~/software>. Type “Visual Studio Enterprise” in the search bar and you should find what you are looking for:
* How to find Visual studio on the azure portal, by looking for visual studio

1. Download and install Visual Studio (leave all the options on their default settings).

* Before clicking install, make sure to check “.NET Desktop Development”
* **If you are installing Visual Studio 2019, click the dropdown for .NET Desktop Development and check “.NET SDK (out of support)”.** You do not have to do this for Visual Studio 2022
* The Visual studio installation interface

1. Enter the product key you obtained previously, following [the instructions in the documentation](https://learn.microsoft.com/en-us/visualstudio/ide/how-to-unlock-visual-studio?view=vs-2019). Normally, clicking on “View key” on the screen pictured in the fourth step above should give you access to a key, that you simply need to copy-and-paste in the menu you can access on Visual Studio by clicking on “Select File” → “Account Settings” → “License with a Product Key”.

##### For Mac

Download a version of Visual Studio at <https://visualstudio.microsoft.com/vs/mac/>. It differs a bit from the Windows version, but that should not impact your experience in this class. The only Visual Studio feature we rely on is the ability to create “Console Apps with C#”, which is equally available in both the Windows and Mac versions.

#### Installing MonoDevelop On Your Own Computer

Unfortunately, MonoDevelop offers pre-packaged release only for linux distributions

* If you are using linux (e.g. Ubuntu, Debian, etc.), then please head out to [MonoDevelop’s download page](https://www.monodevelop.com/download/#fndtn-download-lin).
* If you are using MacOS, you can [have a look at the compilation instructions](https://www.monodevelop.com/developers/building-monodevelop/#macos), but it is very likely that you will find them impossible to understand.
* If you are using Windows, you can [have a look at the compilation instructions](https://www.monodevelop.com/developers/building-monodevelop/#windows), but it is very likely that you will find them impossible to understand.

#### Installing Rider On Your Own Computer

You can download Rider [from their website](https://www.jetbrains.com/rider/download/), for any operating system. Note that, as a student, you can [obtain a licence for free](https://www.jetbrains.com/community/education): simply [fill out this form](https://www.jetbrains.com/shop/eform/students), making sure you use your @augusta.edu email account, and you should receive a free licence instantaneously!

Note that Jetbrains offers to use a SHA-256 checksum (for instance, [for the linux version](https://download.jetbrains.com/rider/JetBrains.Rider-2022.2.2.tar.gz.sha256)) for you to check that your download has not been tampered with. In any case, you can [consult their detailed instructions](https://www.jetbrains.com/help/rider/Installation_guide.html#standalone) to install and execute Rider on any operating system.

### Installing a Code Editor On Your Own Computer

IDE in general performs the operation of setting up the compiler for you, but if you are willing to try to do it yourself, you can then access a larger offering of editors. Indeed, an alternative to installing an IDE is to install a C# compiler on one hand, and a code editor on the other hand (which is just a text editor with some completion or visualization related to the programming language you are using).

Among other code editors suited for C# code, we can mention:

* [RosalynPad](https://roslynpad.net/),
* [Geany](https://www.geany.org/),
* [LinqPad](https://www.linqpad.net/).

We give below some indications on how to set-up Geany.

#### Installing Geany On Your Own Computer

Note:

*This method will only allow you edit and compile individual .cs files, and will not compile C# Solution Projects. To set-up Geany so that you can compile projects, could start by reading* [*this exchange*](https://stackoverflow.com/q/54041013) *(which is about projects in Linux, but applies equally well to projects in C#) or* [*this one*](https://stackoverflow.com/q/8264323)*.*

You can download Geany [from their website](https://www.geany.org/), for any operating system. To use Geany as a text editor for C#, we must download the Mono C# compiler [from their website](https://www.mono-project.com/download/stable/). Make sure to download the most recent version to assure your compiler has the most up-to-date version of “.NET”.

Once you installed Mono, locate the “csc.bat”, “csc.exe” or “csc” file in Mono’s “bin” folder and copy the file path. This path can be of the form

C:\Program Files (x86)\Mono\bin\csc.bat

on windows, or

/usr/bin/csc

on Unix systems.

Now open a .cs file using Geany. Click the arrow next to the “Build” Button and click “Set Build Commands” from the dropdown menu.

Accessing the menu to set build commands

In the “Set Build Commands” window, erase the entry next to the “Compile” button and paste the file path to the “csc.bat” in quotation marks. After the file path, create a single space followed by “%f” with the quotaion marks. All in all, you should have something of the form

"C:\Program Files (x86)\Mono\bin\csc.bat" "%f"

in the “Command” field of the “Compile” line.

Confirm the change by clicking OK and now you will be able to compile, build, and execute **standalone** .cs files.

Setting the build commands

#### Installing Anything Anywhere

If the IDE you would like to adopt is not available for your operating system, you can use a [Virtual Machine](https://en.wikipedia.org/wiki/Virtual_machine) manager to execute a linux-based distribution or a Windows image on top of your operating system.

For this, and regardless of your current operating system, you will need a [Virtual Machine](https://en.wikipedia.org/wiki/Virtual_machine) manager.

1. There are many (free) options to choose from, let us mention
   1. [Virtual Box](https://www.virtualbox.org/) (for Windows, Linux and Mac),
   2. [QEMU](https://www.qemu.org) (for Windows, Linux and Mac),
   3. [Hyper-V](https://learn.microsoft.com/en-us/virtualization/hyper-v-on-windows/quick-start/enable-hyper-v) (for Windows),
2. Download a version of “Microsoft Operating Systems” from [Azure Dev Tools for Teaching](https://aka.ms/devtoolsforteaching), or a Linux-based distribution (typically, [ubuntu](https://ubuntu.com/appliance/vm) has a good reputation of being accessible and user-friendly).
3. Install and execute your version of Windows or Linux from your virtual machine, and follow the corresponding instructions to install the IDE you are interested in.

Note that [it is illegal to execute macOS in a virtual environment that is not hosted on a mac computer](https://law.stackexchange.com/q/18282), which drastically reduces the interest for you to consider this option.

### Accessing One of the Computers in a Computer Lab

Please refer to [this page from AU’s Information Technology](https://my.augusta.edu/it/computers-printing.php#walkinlabs) to know where the computer labs are located. Visual Studio should be pre-installed on every computer.

### Compiling Code On-Line

*As a backup or only to test snippets of code*, you can compile C# code online. Multiple online platforms exist, such as:

* <https://www.browxy.com/>
* <https://www.tutorialspoint.com/compile_csharp_online.php>
* <https://www.onlinegdb.com/online_csharp_compiler>
* <https://www.jdoodle.com/compile-c-sharp-online/>
* <https://dotnetfiddle.net/>
* <https://www.w3schools.com/CS/trycs.php?filename=demo_helloworld>

Note that none of them are endorsed by the school and that they can pose security and privacy challenges: never enter any sensitive information and do not rely on them too heavily. However, they can be a good support if you would like to test a short snippet of code but do not have access at the moment to a computer with an IDE installed.

# (Un)Zipping Archives

This short note explains how to

* Unzip files,
* Zip folders,
* Locate your project

for the three main operating systems (Windows, Linux and macOS).

## Unzipping Files

### Windows

Navigate your file explorer and navigate to your Downloads folder (or wherever you downloaded the file). From there, look for the file you downloaded, right-click, and select “Extract All…”. When the “Extract Compressed (Zipped) Folder” window opens, click the “Extract” button.

### Linux

This guide is assuming you have Zip/Unzip installed on your Linux distribution. If this is not the case, first follow this [install guide](https://www.tecmint.com/install-zip-and-unzip-in-linux/).

#### Using the graphical interface

Normally, a simple [right click and choose “Extract” or “Open with Ark”](https://www.wikihow.tech/Unzip-Files-in-Linux) should do it.

#### Using the Command-Line

Navigate to your command-line interface and execute the following command (as a normal user, as indicated by $):

$ unzip [FileName].zip

where “[FileName].zip” is the name of the zip file.

### macOS

Simply double-click on the zip file to unzip it onto your desktop.

## Zipping Files

### Windows

Navigate to your file explorer and go to where your solution is stored on your system, the default file path being:

C:\Users\[UserName]\source\repos

where “[UserName]” is your Windows username (on school computers, this should be your AU username). Right click the folder you want to zip, go down the list to the “Send to” option, and then click on the “Compressed (Zipped) Folder” option. This should then create a new zip file.

### Linux

#### Using the graphical interface

Normally, a simple [right click and choose “Compress”](https://www.wikihow.com/Make-a-Zip-File-in-Linux) should do it.

#### Using the Command-Line

Navigate to your command-line interface and execute the following command (as a normal user, as indicated by $):

$ zip -r [ZipFileName].zip [FileName]

where “[ZipFileName].zip” is the name you want for the zip file, and “[FileName]” for the folder you want to zip.

### macOS

Navigate to your file explorer and go to where your solution is stored on your system, the default file path being:

[UserName]\source\repos

where “[UserName]” is your Mac username. Right-click on the folder that you want to zip up and click on the “Compress the Folder” option.

## But Where Is My Project?

By default, it *should* be stored in a folder located in

C:\Users\[UserName]\source\repos

for Windows users,

[UserName]\source\repos

for macOS users,

/home/[UserName]/Projects

for Linux users.

When in doubt, open your project in the IDE, right-click on the solution, and look for an option called “Open in File Explorer” or “Open Containing Folder”:

A drop-down menu containing the choice Open in containing folder.

# Keyboard Shortcuts

## Foreword

This document contains useful keyboard shortcuts for different operating systems and IDEs. We use the following symbols:

| Symbol | Common Name |
| --- | --- |
| ⇧ | Shift |
| ⌥ | Option (or Alt) |
| ⌘ | Command (or Cmd) |
| ↵ | (Carriage) Return |

The sections labeled with the star symbol (“\*”) work generally everywhere, beyond your IDE.

More advanced shortcuts may be available to your particular IDE:

* For Visual Studio for Windows, refer to [the documentation](https://docs.microsoft.com/en-us/visualstudio/ide/default-keyboard-shortcuts-in-visual-studio?view=vs-2019),
* For Visual Studio for MacOS, refer to [the documentation](https://docs.microsoft.com/en-us/visualstudio/mac/keyboard-shortcuts?view=vsmac-2019)
* For Rider, refer to [the documentation](https://www.jetbrains.com/help/rider/mastering_keyboard_shortcuts.html),
* For MonoDevelop, you can refer to [this cheatsheet](https://shortcutworld.com/Xamarin-Studio/win/Xamarin-Studio-(MonoDevelop)_Shortcuts) or directly access [the key binding panel](https://mhut.ch/journal/2011/02/05/monodevelop-tips-key-bindings).

## Useful Shortcuts

### Build solution

| OS | Keys |
| --- | --- |
| Linux | Ctrl + ⇧ + B |
| MacOS | ⌘ + B |
| Windows | Ctrl + ⇧ + B |

### Exit any program\*

| OS | Keys |
| --- | --- |
| Linux | Alt + F4 or Ctrl + q |
| MacOS | ⌘ + q |
| Windows | Alt + F4 |

### Redo\*

| OS | Keys |
| --- | --- |
| Linux | Ctrl + y |
| MacOS | ⌘ + y |
| Windows | Ctrl + y |

### Run/execute program

| OS | Keys |
| --- | --- |
| Linux | Ctrl + F5 |
| MacOS | F5 -or- ⌥ + ⌘ + ↵ |
| Windows | Ctrl + F5 |

### Save\*

| OS | Keys |
| --- | --- |
| Linux | Ctrl + s |
| MacOS | ⌘ + s |
| Windows | Ctrl + s |

### Save All\*

| OS | Keys |
| --- | --- |
| Linux | Ctrl + ⇧ + s |
| MacOS | ⌘ + ⇧ + s |
| Windows | Ctrl + ⇧ + s |

### Undo\*

| OS | Keys |
| --- | --- |
| Linux | Ctrl + z |
| MacOS | ⌘ + z |
| Windows | Ctrl + z |

### Comment Code Selection

| OS | Keys |
| --- | --- |
| Linux | Ctrl + k + c |
| MacOS | ⌘ + k + c |
| Windows | Ctrl + k + c |

### Uncomment Code Selection

| OS | Keys |
| --- | --- |
| Linux | Ctrl + k + u |
| MacOS | ⌘ + k + u |
| Windows | Ctrl + k + u |

# Datatypes in C

## Value Types

### Numeric

#### Signed Integer

| Type | Range | Size |
| --- | --- | --- |
| sbyte | -128 to 127 | Signed 8-bit integer |
| short | -32,768 to 32,767 | Signed 16-bit integer |
| int | -2,147,483,648 to 2,147,483,647 | Signed 32-bit integer |
| long | -9,223,372,036,854,775,808 to 9,223,372,036,854,775,807 | Signed 64-bit integer |

#### Unsigned Integer

| Type | Range | Size |
| --- | --- | --- |
| byte | 0 to 255 | Unsigned 8-bit integer |
| ushort | 0 to 65,535 | Unsigned 16-bit integer |
| uint | 0 to 4,294,967,295 | Unsigned 32-bit integer |
| ulong | 0 to 18,446,744,073,709,551,615 | Unsigned 64-bit integer |

#### Floating-point Numbers

| Type | Approximate Range | Precision |
| --- | --- | --- |
| float | ±1.5e−45 to ±3.4e38 | 7 digits |
| double | ±5.0e−324 to ±1.7e308 | 15–16 digits |
| decimal | (-7.9 x 1028 to 7.9 x 1028)/(100 to 1028) | 28–29 significant digits |

### Logical

| Type | Possible Values | Size |
| --- | --- | --- |
| bool | true, false | 8-bit |

### Character

| Type | Range | Size |
| --- | --- | --- |
| char | U+0000 to U+ffff | Unicode 16-bit character |

## Literals

| Name | Corresponding datatype | Examples |
| --- | --- | --- |
| Integer Literal | int | 40, -39, 291838, 0, … |
| Float Literal | float | 3.5F, -43.5f, 309430.70006F, … |
| Double Literal | double | 28.98, 239.0, -391.089, 0.0, … |
| Decimal Literal | decimal | 8.95m, 3283.9M, -30m, … |
| Boolean Literal | bool | true, false |
| Character Literal | char | 'Y', 'a', '0', '\n', '\x0058', '\u0058', … |

## Compatibility

This table is to be read as

means that those values or variables from the datatypes in the row and column can be “operated together” (meaning, you can for instance multiply them), ✘ means that those values or variables from the datatypes in the row and column can*not* be “operated together” (meaning, you can*not* for instance multiply them).

|  | **Integer Literal** | **Float Literal** | **Double Literal** | **Decimal Literal** |
| --- | --- | --- | --- | --- |
| int |  | ✘ | ✘ | ✘ |
| float |  |  | ✘ | ✘ |
| double |  |  |  | ✘ |
| decimal |  | ✘ | ✘ |  |

## Result Type of Operations

|  | int | float | double | decimal |
| --- | --- | --- | --- | --- |
| int | int | float | double | decimal |
| float | float | float | double | illegal |
| double | double | double | double | illegal |
| decimal | decimal | illegal | illegal | decimal |

This table is to be read as

Values or variables from the datatypes in the row and column can be “operated together” and will produce the datatype indicated in the cell, or cannot be “operated together” if the value in the cell is “illegal”.

## References

* <https://docs.microsoft.com/en-us/dotnet/csharp/tour-of-csharp/types-and-variables>
* <https://docs.microsoft.com/en-us/dotnet/csharp/language-reference/keywords/integral-types-table>
* <https://docs.microsoft.com/en-us/dotnet/csharp/language-reference/keywords/floating-point-types-table>
* <https://docs.microsoft.com/en-us/dotnet/csharp/language-reference/keywords/value-types-table>
* <https://docs.microsoft.com/en-us/dotnet/csharp/language-reference/keywords/implicit-numeric-conversions-table>
* <https://docs.microsoft.com/en-us/dotnet/csharp/language-reference/keywords/explicit-numeric-conversions-table>

# UML Class Diagrams

## General Rules

### Attributes and Properties

| Type of Attribute or Property |  |
| --- | --- |
| Public attribute | + attribute : [data type] |
| Private attribute | - attribute : [data type] |
| Public property | + «property» Property : [data type] |
| Private property | - «property» Property : [data type] |

### Methods with Return Type

| Type of Method |  |
| --- | --- |
| Public method with no arguments | + Method() : [return type] |
| Private method with no arguments | - Method() : [return type] |
| Public method with arguments | + Method(argument1 : [data type 1], …, argumentn : [data type n]) : [return type] |
| Private method with arguments | - Method(argument1 : [data type 1], …, argumentn : [data type n]) : [return type] |

### Methods with Void or No Return Type

| Type of Method |  |
| --- | --- |
| Public method with arguments | + Method(argument1 : [data type 1],…, argumentn : [data type n]) |
| Private method with arguments | - Method(argument1 : [data type 1],…, argumentn : [data type n]) |

### Special Cases

| Case | How to Change UML Formatting |
| --- | --- |
| Static | Underline |
| Abstract | Italicize |
| Protected | # instead of + or - |
| Abstract class | Add «Abstract» above class name |
| Interface | Add «Interface» above class name |

### Relationships (Arrows)

| Arrow Type | What It Means |
| --- | --- |
| Open arrow with solid line (⇽) | Inheritance |
| Open arrow with dashed line (◁┈) | Realization |

## Examples

### Simple Example

For example, in the following UML class diagram:

A UML diagram for the ExampleClass1 class (text version, image version, svg version)

#### Attributes

* attr1 is private and of type string,
* attr2 is public and of type int,

#### Properties

* Prop1 is a public property of type char (that may have both a set and a get, or only one of them),
* Prop2 is a public property of type double that must contain both a set and a get,
* Prop3 is a private property of type float that contains only a get and no set,

#### Methods

* Method1 is a public method that takes as an argument a sbyte and returns a short,
* Method2 is a public method that takes as an argument a long and does not return anything (that is, its return type is void, here omitted),
* Method3 is a public *abstract* method that does not take any argument and returns a string,
* Method4 is a public *static* method that does not take any argument and returns a char.

#### Constructors

* The first ExampleClass1 is a public constructor that does not take any argument (and does not have any return type),
* The second ExampleClass1 is a private constructor (we know it even if the indication «constructor» is missing, since it has the same name as the class) that takes as an argument a bype (and does not have any return type)

## Forbidden Combination

Note that the following does not make sense:

* A static method cannot be abstract,
* An attribute cannot be abstract,

# Computers and Programming

## Principles of Computer Programming

* Computer hardware changes frequently - from room-filling machines with punch cards and tapes to modern laptops and tablets - and will continue doing so.
* With these changes, the capabilities of computers increase rapidly (storage, speed, graphics, etc.)
* Computer programming languages also change
  + Better programming language theory leads to new programming techniques
  + Improved programming language implementations
  + New languages are created, old ones updated
* There are [hundreds of programming languages](https://en.wikipedia.org/wiki/List_of_programming_languages), why?
  + Different tools for different jobs
    - Some languages are better suited for certain jobs
    - For example, Python is best for scripting, Javascript is best for web pages, MySQL is best for databases, etc.
  + Personal preference and popularity
* This class is about “principles” of computer programming
  + Common principles behind all languages will not change, even though hardware and languages do
  + How to organize and structure data
  + How to express logical conditions and relations
  + How to solve problems with programs

## Programming Language Concepts

We begin by discussing three categories of languages manipulated by computers. We will be studying and writing programs in *high-level languages*, but understanding their differences and relationships to other languages[[4]](#footnote-4) is of importance to become familiar with them.

* Machine language
  + Computers are made of electronic circuits
    - Circuits are components connected by wires
    - Some wires carry data - e.g. numbers
    - Some carry control signals - e.g. do an add or a subtract operation
  + Instructions are settings on these control signals
    - A setting is represented as a 0 or 1
    - A machine language instruction is a group of settings - For example: 1000100111011000
  + Most CPUs use one of two languages: x86 or ARM
* Assembly language
  + Easier way for humans to write machine-language instructions
  + Instead of 1s and 0s, it uses letters and “words” to represent an instruction.
    - Example x86 instruction:
  + MOV BX, AX
  + which makes a copy of data stored in a component called AX and places it in one called BX
  + **Assembler**: Translates assembly language instructions to machine language instructions
    - For example: MOV BX, AX translates into 1000100111011000
    - One assembly instruction = one machine-language instruction
    - x86 assembly produces x86 machine code
  + Computers can only execute the machine code
* High-level language
  + Hundreds including C#, C++, Java, Python, etc.
  + Most programs are written in a high-level language since:
    - More human-readable than assembly language
    - High-level concepts such as processing a collection of items are easier to write and understand
    - Takes less code since each statement might be translated into several assembly instructions
  + **Compiler**: Translates high-level language to machine code
    - Finds “spelling” errors but not problem-solving errors
    - Incorporates code libraries – commonly used pieces of code previously written such as Math.Sqrt(9)
    - Optimizes high-level instructions – your code may look very different after it has been optimized
    - Compiler is specific to both the source language and the target computer
  + Compile high-level instructions into machine code then execute since computers can only execute machine code

A Visual Representation of the Relationships Between Languages

A more subtle difference exists between high-level languages. Some (like C) are *compiled* (as we discussed above), some (like Python) are *interpreted*, and some (like C#) are in an in-between called *managed*.

* Compiled vs. Interpreted languages
  + Not all high-level languages use a compiler - some use an interpreter
  + **Interpreter**: Lets a computer “execute” high-level code by translating one statement at a time to machine code
  + Advantage: Less waiting time before you can execute the program (no separate “compile” step)
  + Disadvantage: Program executes slower since you wait for the high-level statements to be translated then the program is executed
* Managed high-level languages (like C#)
  + Combine features of compiled and interpreted languages
  + Compiler translates high-level statements to **intermediate language** instructions, not machine code
    - Intermediate language: Looks like assembly language, but not specific to any CPU
  + **run-time** executes by *interpreting* the intermediate language instructions - translates one at a time to machine code
    - Faster since translation is partially done already (by compiler), only a simple “last step” is done when executing the program
  + Advantages of managed languages:
    - In a “non-managed” language, a compiled program only works on one OS + CPU combination (**platform**) because it is machine code
    - Managed-language programs can be reused on a different platform without recompiling - intermediate language is not machine code and not CPU-specific
    - Still need to write an intermediate language interpreter for each platform (so it produces the right machine code), but, for a non-managed language, you must write a compiler for each platform
    - Writing a compiler is more complicated and more work than writing an interpreter thus an interpreter is a quicker (and cheaper) way to put your language on different platforms
    - Intermediate-language interpreter is much faster than a high-level language interpreter, so programs execute faster than an “interpreted language” like Python
  + This still executes slower than a non-managed language (due to the interpreter), so performance-minded programmers use non-managed compiled languages (e.g. for video games)

A Visual Representation of the Differences Between High-Level Languages

## Software Concepts

* Flow of execution in a program
  + Program receives input from some source, e.g. keyboard, mouse, data in files
  + Program uses input to make decisions
  + Program produces output for the outside world to see, e.g. by displaying images on screen, writing text to console, or saving data in files
* Program interfaces
  + **GUI** or Graphical User Interface: Input is from clicking mouse in visual elements on screen (buttons, menus, etc.), output is by drawing onto the screen
  + **CLI** or Command Line Interface: Input is from text typed into “command prompt” or “terminal window,” output is text printed at same terminal window
  + This class will use CLI because it is simple, portable, easy to work with – no need to learn how to draw images, just read and write text

## Programming Concepts

### Programming workflow

Flowchart demonstrating roles and tasks of a programmer, beta tester and user in the creation of programs.

The workflow of the programmer will differ a bit depending on if the program is written in a compiled or an intprepreted programming language. From the distance, both looks like what is pictured in the [the flowchart demonstrating roles and tasks of a programmer, beta tester and user in the creation of programs](#fig:flowchart1), but some differences remain:

* Compiled language workflow
  + Writing down specifications
  + Creating the source code
  + Running the compiler
  + Reading the compiler’s output, warning and error messages
  + Fixing compile errors, if necessary
  + Executing and testing the program
  + Debugging the program, if necessary
* Interpreted language workflow
  + Writing down specifications
  + Creating the source code
  + Executing the program in the interpreter
  + Reading the interpreter’s output, determining if there is a syntax (language) error or the program finished executing
  + Editing the program to fix syntax errors
  + Testing the program (once it can execute with no errors)
  + Debugging the program, if necessary

Interpreted languages have

* **Advantages**: Fewer steps between writing and executing, can be a faster cycle
* **Disadvantages**: All errors happen when you execute the program, no distinction between syntax errors (compile errors) and logic errors (bugs in executing program)

### (Integrated) Development Environment

Programmers can either use a collection of tools to write, compile, debug and execute a program, or use an “all-in-one” solution called an Integrated Development Environment (IDE).

* The [“Unix philosophy”](https://en.wikipedia.org/wiki/Unix_philosophy) states that a program should do only one task, and do it properly. For programmers, this means that
  + One program will be needed to edit the source code, a text editor (it can be Geany, notepad, kwrite, emacs, sublime text, vi, etc.),
  + One program will be needed to compile the source code, a compiler (for C#, it will be either [mono](https://en.wikipedia.org/wiki/Mono_(software)) or [Roslyn](https://en.wikipedia.org/wiki/Roslyn_(compiler)),
  + Other programs may be needed to debug, execute, or organize larger projects, such as makefile or [MKBundle](https://www.mono-project.com/docs/tools+libraries/tools/mkbundle/).

IDE “bundle” all of those functionality into a single interface, to ease the workflow of the programmer. This means sometimes that programmers have fewer control over their tools, but that it is easier to get started.

* Integrated Development Environment (IDE)
  + Combines a text editor, compiler, file browser, debugger, and other tools
  + Helps you organize a programming project
  + Helps you write, compile, and test code in one place

In particular, Visual Studio is an IDE, and it uses its own vocabulary:

* Solution: An entire software project, including source code, metadata, input data files, etc.
* “Build solution”: Compile all of your code
* “Start without debugging”: Execute the compiled code
* Solution location: The folder (on your computer’s file system) that contains the solution, meaning all your code and the information needed to compile and execute it

# C# Fundamentals

## Introduction to the C# Language

* C# is a managed language (as [discussed previously](https:/princomp.github.io/lectures/intro/computers_and_programming#programming-language-concepts))
  + Write in a high-level language, compile to intermediate language, run intermediate language in interpreter
  + Intermediate language is called CIL (Common Intermediate Language)
  + Interpreter is called .NET run-time
  + Standard library is called .NET Framework, comes with the compiler and run-time
* It is widespread and popular
  + It is [“programming language of the year 2023”](https://www.tiobe.com/tiobe-index/) in the very well-respected [TIOBE Index](https://en.wikipedia.org/wiki/TIOBE_index).
  + It was the first in the list of [“3 Future Programming Languages You Should Learn Between 2022 and 2030”](https://betterprogramming.pub/3-future-programming-languages-you-should-learn-between-2022-and-2030-8a618a15eca6), because of the growing popularity of [Unity](https://unity.com/).
  + [7th most “desired / admired” language on StackOverflow](https://survey.stackoverflow.co/2023/#programming-scripting-and-markup-languages)
  + .NET is the [first most used “other” library/framework](https://survey.stackoverflow.co/2023/#most-popular-technologies-misc-tech)
  + More insights on its evolution can be found [in this blog post](https://dottutorials.net/stats-surveys-about-net-core-future-2020/#stackoverflow-surveys).

## The Object-Oriented Paradigm

* C# is called an “object-oriented” language
  + Programming languages have different *paradigms*: philosophies for organizing code, expressing ideas
  + Object-oriented is one such paradigm, C# uses it
  + Meaning of object-oriented: Program mostly consists of *objects*, which are reusable modules of code
  + Each object contains some data (*attributes*) and some functions related to that data (*methods*)
* Object-oriented terms
  + **Class**: A blueprint or template for an object. Code that defines what kind of data the object will contain and what operations (functions) you will be able to do with that data
  + **Object**: A single instance of a class, containing running code with specific values for the data. Each object is a separate “copy” based on the template given by the class.  
    Analogy: A *class* is like a floorplan while an *object* is the house build from the floorplan. Plus, you can make as many houses as you would like from a single floorplan.
  + **Attribute**: A piece of data stored in an object.  
    Example: A *House* class has a spot for a color property while an house object has a color (e.g. “Green”).
  + **Method**: A function that modifies an object. This code is part of the class, but when it is executed, it modifies only a specific object and not the class.  
    Example: A *House* class with a method to change the house color. Using this method changes the color a single house object but does not change the *House* class or the color on any other house objects.
* Examples:
  + A Car *Class*
    - Attributes: Color, engine status (on/off), gear position
    - Methods: Press gas or brake pedal, turn key on/off, shift transmission
  + A Car *Object*  
    Example: A *Porsche911* object that is Red, Engine On, and in 1st gear
  + An “Audio File” *Class* represents a song being played in a music player
    - Attributes: Sound wave data, current playback position, target speaker device
    - Methods: Play, pause, stop, fast-forward, rewind
  + An Audio File *Object*  
    Example: A *NeverGonnaGiveYouUp* object that is “rolled wave data”, 0:00, speaker01

## First Program

It is customary to start the study of a programming language with a [“Hello World” program](https://en.wikipedia.org/wiki/%22Hello,_World!%22_program), that simply displays “Hello World”. It is a simple way of seeing a first, simple example of the basic structure of a program. Here’s a simple “hello world” program in the C# language:

### Hello World

/\* I'm a multi-line comment,  
 \* I can span over multiple lines!  
 \*/  
using System;  
  
class Program  
{  
 static void Main()  
 {  
 Console.WriteLine("Hello, world!"); // I'm an in-line comment.  
 }  
}

Features of this program:

* A multi-line comment: everything between the /\* and \*/ is considered a *comment*, i.e. text for humans to read. It will be ignored by the C# compiler and has no effect on the program.
* A using statement: This imports code definitions from the System *namespace*, which is part of the .NET Framework (the standard library).
  + In C#, code is organized into **namespaces**, which group related classes together
  + If you want to use code from a different namespace, you need a using statement to “import” that namespace
  + All the standard library code is in different namespaces from the code you will be writing, so you’ll need using statements to access it
* A class declaration[[5]](#footnote-5)
  + Syntax:
* class [name of class]  
   {  
   [body of the class]  
   }
  + All code between opening { and closing } is the *body* of the class named by the class [name of class] statement
* A method declaration
  + A collection of instructions with a name
  + Can be used by typing its name
  + A method is similar to a paragraph, in that it can contain multiple statements, and a class is similar to a chapter, in that it can have multiple methods within its body.
  + A C# program requires a method called Main, and, in our example, is followed by empty parentheses (we will get to those later, but they are required)
  + Just like the class declaration, the body of the method beings with { and ends with }
* A statement inside the body of the method:
* Console.WriteLine("Hello, world!"); // I'm an in-line comment.
  + This is the part of the program that actually “does something”: It displays a line of text to the console:
  + A terminal displaying the result of the execution: the text Hello World
  + This statement contains a class name (Console), followed by a method name (WriteLine). It calls the WriteLine method in the Console class.
  + The **argument** to the WriteLine method is the text “Hello, world!”, which is in parentheses after the name of the method. This is the text that gets printed in the console: The WriteLine method (which is in the standard library) takes an argument and prints it to the console.
  + Note that the argument to WriteLine is inside double-quotes. This means it is a **string**, i.e. textual data, not a piece of C# code. The quotes are required in order to distinguish between text and code.
  + A statement *must* end in a semicolon (the class header and method header are not statements)
* An in-line comment: All the text from the // to the end of the line is considered a comment, and is ignored by the C# compiler.

## Rules of C# Syntax

* Each statement must end in a semicolon (;), except for some statements that we will study in the future that contains opening { and closing }, that do not end in a ;.
  + Note that class and method declarations, as well as comments, [are not statements](https://docs.microsoft.com/en-us/dotnet/csharp/programming-guide/statements-expressions-operators/statements) and hence do not need to ends with a ;. Typically, a method *contains* some statements, but it is not a statement.
* All words are case-sensitive
  + A class named Program is not the same as one named program
  + A method named writeline is not the same as one named WriteLine
* Braces and parentheses must always be matched
  + Once you start a class or method definition with {, you must end it with }
* Blank space has *almost* no meaning
  + Blank spaces refer to spaces (sometimes denoted “ ”, “␣” or “⌴”), [tabs](https://en.wikipedia.org/wiki/Tab_key#Tab_characters) (which consists in 4 spaces), and new lines (sometimes denoted “↵”, “↩”, “←” or “⏎”)
  + There must be at least 1 space between words
  + Other than that, spaces and new lines are just to help humans read the code
  + Spaces are counted exactly if they are inside string data, e.g. "Hello world!" is different from "Hello world!"
  + Otherwise, entire program could be written on one line[[6]](#footnote-6); it would have the same meaning
* All C# applications must have a Main method
  + Name must match exactly, otherwise .NET run-time will get confused
  + This is the first code to execute when the application starts – any other code (in methods) will only execute when its method is called

## Conventions of C# Programs

* Conventions: Not enforced by the compiler/language, but expected by humans
  + Program will still work if you break them, but other programmers will be confused
* Indentation
  + After a class or method declaration (header), put the opening { on a new line underneath it
  + Then indent the next line by 4 spaces, and all other lines “inside” the class or method body
  + De-indent by 4 spaces at end of method body, so ending } aligns vertically with opening {
  + Method definition inside class definition: Indent body of method by another 4 spaces
  + In general, any code between { and } should be indented by 4 spaces relative to the { and }
* Code files
  + C# code is stored in files that end with the extension “.cs”
  + Each “.cs” file contains exactly one class
  + The name of the file is the same as the name of the class (Program.cs contains class Program)

Note that some of those conventions are actually rules in different programming languages (typically, the last two regarding code files are mandatory rules in java).

## Reserved Words and Identifiers

* Reserved words: Keywords in the C# language
  + Note they have a distinct color in the code sample and in your IDE
  + Built-in commands/features of the language
  + Can only be used for one specific purpose; meaning cannot be changed
  + Examples:
    - using
    - class
    - public
    - private
    - namespace
    - this
    - if
    - else
    - for
    - while
    - do
    - return
  + There is no need to memorize [the whole list of keywords](https://docs.microsoft.com/en-us/dotnet/csharp/language-reference/keywords/), as we will only introduce the ones we need on a “per need” basis.
* Identifiers: Human-chosen names
  + Names for classes (Rectangle, ClassRoom, etc.), variables (age, name, etc.), methods (ComputeArea, GetLength, etc), namespaces, etc.
  + Some have already been chosen for the standard library (e.g. system, Console, WriteLine, Main), but they are still identifiers, not keywords
  + Rules for identifiers:
    - Must not be a reserved word
    - Must contain only letters (lower case, from a to z, or upper case, from A to Z), numbers (made of digits from 0 to 9), and underscore (\_). But they cannot contain spaces.
    - Must not begin with a number
    - Are case sensitive
    - Must be unique (you cannot re-use the same identifier twice in the same scope – a concept we will discuss later)
  + Conventions for identifiers
    - Should be descriptive, e.g. “AudioFile” or “userInput” not “a” or “x”
    - Should be easy for humans to read and type
    - If name is multiple words, use [CamelCase](https://en.wikipedia.org/wiki/Camel_case) (or its variation [Pascal case](https://www.c-sharpcorner.com/UploadFile/8a67c0/C-Sharp-coding-standards-and-naming-conventions/)) to distinguish words, e.g. myHeightInMeters or distanceFromEarthToMoon.
    - Class and method names should start with capitals, e.g. “class AudioFile”
    - Variable names should start with lowercase letters, then capitalize subsequent words, e.g. “myFavoriteNumber”

## Write and WriteLine

* The WriteLine method
  + We saw this in the “Hello World” program: Console.WriteLine("Hello World!"); results in “Hello World!” being displayed in the terminal
  + In general, Console.WriteLine("text"); will display the text but not the “’s in the terminal, then *start a new line*
  + This means a second Console.WriteLine will display its text on the next line of the terminal. For example, this program:
  + using System;  
      
    class Welcome  
    {  
     static void Main()  
     {  
     Console.WriteLine("Hello");  
     Console.WriteLine("World!");  
     }  
    }
  + will display the following output in the terminal:
  + Hello  
    World!
* Methods with multiple statements
  + Note that our two-line example has a Main method with multiple statements
  + In C#, each statement must end in a semicolon
  + Class and method declarations are not statements
  + Each line of code in your .cs file is not necessarily a statement
  + A single invocation/call of the WriteLine method is a statement
* The Write method
  + Console.WriteLine("text") prints the text, then starts a new line in the terminal – it effectively “hits enter” after printing the text
  + Console.Write("text") just prints the text, without starting a new line. It’s like typing the text without hitting “enter” afterwards.
  + Even though two Console.Write calls are two statements, and appear on two lines, they will result in the text being printed on just one line. For example, this program:
  + using System;  
      
    class Welcome  
    {  
     static void Main()  
     {  
     Console.Write("Hello");  
     Console.Write("World!");  
     }  
    }
  + will display the following output in the terminal:
  + HelloWorld!
  + Note that there is no space between “Hello” and “World!” because we did not type one in the argument to Console.Write
* Combining Write and WriteLine
  + We can use both WriteLine and Write in the same program
  + After a call to Write, the “cursor” is on the same line after the printed text; after a call to WriteLine the “cursor” is at the beginning of the next line
  + This program:
  + using System;  
      
    class Welcome  
    {  
     static void Main()  
     {  
     Console.Write("Hello ");  
     Console.WriteLine("World!");  
     Console.Write("Welcome to ");  
     Console.WriteLine("CSCI 1301!");  
     }  
    }
  + will display the following output in the terminal:
  + Hello world!  
    Welcome to CSCI 1301!

## Escape Sequences

* Explicitly writing a new line
  + So far we’ve used WriteLine when we want to create a new line in the output
  + The **escape sequence** \n can also be used to create a new line – it represents the “newline character,” which is what gets printed when you type “enter”
  + This program will produce the same output as our two-line “Hello World” example, with each word on its own line:
  + using System;  
      
    class Welcome  
    {  
     static void Main()  
     {  
     Console.Write("Hello\nWorld!\n");  
     }  
    }
* Escape sequences in detail
  + An **escape sequence** uses “normal” letters to represent “special”, hard-to-type characters
  + \n represents the newline character, i.e. the result of pressing “enter”
  + \t represents the tab character, which is a single extra-wide space (you usually get it by pressing the “tab” key)
  + \" represents a double-quote character that will get printed on the screen, rather than ending the text string in the C# code.
    - Without this, you couldn’t write a sentence with quotation marks in a Console.WriteLine, because the C# compiler would assume the quotation marks meant the string was ending
    - This program will not compile because in quotes is not valid C# code, and the compiler thinks it is not part of the string:
    - // Incorrect Code  
      class Welcome  
      {  
       static void Main()  
       {  
       Console.WriteLine("This is "in quotes"");  
       // This is parsed as if the string was "This is "  
       // followed by in quotes, which is not valid C#,  
       // followed by the empty string "".  
       }  
      }
    - This program will display the sentence including the quotation marks:
    - using System;  
        
      class Welcome  
      {  
       static void Main()  
       {  
       Console.WriteLine("This is \"in quotes\"");  
       }  
      }
  + Note that all escape sequences begin with a backslash character (\), called the “escape character”
  + General format is \[key letter] – the letter after the backslash is like a “keyword” indicating which special character to display. You can refer to the [full list on microsoft documentation](https://learn.microsoft.com/en-us/dotnet/csharp/programming-guide/strings/#string-escape-sequences).
  + If you want to put an actual backslash in your string, you need the escape sequence \\, which prints a single backslash
    - This will result in a compile error because \U is not a valid escape sequence:
    - Console.WriteLine("Go to C:\Users\Edward");
    - This will display the path correctly:
    - Console.WriteLine("Go to C:\\Users\\Edward");

# Datatypes and Variables

## Datatype Basics

* Recall the basic structure of a program
  + Program receives input from some source, uses input to make decisions, produces output for the outside world to see
  + In other words, the program reads some data, manipulates data, and writes out new data
  + In C#, data is stored in objects during the program’s execution, and manipulated using the methods of those objects
* This data has **types**
  + Numbers (the number 2) are different from text (the word “two”)
  + Text data is called “strings” because each letter is a **character** and a word is a *string of characters*
  + Within “numeric data,” there are different types of numbers
    - Natural numbers (ℕ): 0, 1, 2, …
    - Integers (ℤ): … -2, -1, 0, 1, 2, …
    - Real numbers (ℝ): 0.5, 1.333333…, -1.4, etc.
* Basic Datatypes in C#
  + C# uses keywords to name the types of data
  + Text data:
    - string: a string of characters, like "Hello world!"
    - char: a single character, like 'e' or 't'
  + Numeric data:
    - int: An integer, as defined previously
    - uint: An *unsigned* integer, in other words, a natural number (positive integers only)
    - float: A “floating-point” number, which is a real number with a fractional part, such as 3.85
    - double: A floating-point number with “double precision” – also a real number, but capable of storing more significant figures
    - decimal: An “exact decimal” number – also a real number, but has fewer rounding errors than float and double (we will explore the difference later) [[7]](#footnote-7)

## Literals and Variables

### Literals and their types

* A **literal** is a data value written in the code
* A form of “input” provided by the programmer rather than the user; its value is fixed throughout the program’s execution
* Literal data must have a type, indicated by syntax:
  + string literal: text in double quotes, like "hello"
  + char literal: a character in single quotes, like 'a'
  + int literal: a number without a decimal point, with or without a minus sign (e.g. 52)
  + long literal: just like an int literal but with the suffix l or L, e.g. 4L
  + double literal: a number with a decimal point, with or without a minus sign (e.g. -4.5)
  + float literal: just like a double literal but with the suffix f or F (for “float”), e.g. 4.5f
  + decimal literal: just like a double literal but with the suffix m or M(for “deciMal”), e.g. 6.01m

### Variables overview

* Variables store data that can *vary* (change) during the program’s execution
* They have a type, just like literals, and also a name
* You can use literals to write data that gets stored in variables
* Sample program with variables:
* using System;  
    
  class MyFirstVariables  
  {  
   static void Main()  
   {  
   // Declaration  
   int myAge;  
   string myName;  
   // Assignment  
   myAge = 29;  
   myName = "Edward";  
   // Displaying  
   Console.WriteLine(  
   $"My name is {myName} and I am {myAge} years old."  
   );  
   }  
  }
* This program shows three major operations you can do with variables.
  + First it **declares** two variables, an int-type variable named “myAge” and a string-type variable named “myName”
  + Then, it **assigns** values to each of those variables, using literals of the same type. myAge is assigned the value 29, using the int literal 29, and myName is assigned the value “Edward”, using the string literal "Edward"
  + Finally, it **displays** the current value of each variable by using the Console.WriteLine method and **string interpolation**, in which the values of variables are inserted into a string by writing their names with some special syntax (a $ character at the beginning of the string, and braces around the variable names)

## Variable Operations

### Declaration

* This is when you specify the *name* of a variable and its *type*
* The syntax is the type keyword, a space, the name of the variable, then a semi-colon.
* Examples: int myAge;, string myName;, double winChance;.
* A variable name is an identifier, so it should follow the rules and conventions
  + Can only contain letters and numbers
  + Must be unique among all variable, method, and class names
  + Should use CamelCase if it contains multiple words
* Note that the variable’s type is not part of its name: two variables cannot have the same name *even if* they are different types
* Multiple variables can be declared in the same statement: string myFirstName, myLastName; would declare *two* strings called respectively myFirstName and myLastName

### Assignment

* The act of changing the value of a variable
* Uses the symbol =, which is the *assignment operator*, not a statement of equality – it does not mean “equals”
* Direction of assignment is **right to left**: the variable goes on the left side of the = symbol, and its new value goes on the right
* Syntax: variable\_name = value;
* Example: myAge = 29;
* Value *must* match the type of the variable. If myAge was declared as an int-type variable, you cannot write myAge = "29"; because "29" is a string

### Initialization: Declaration and Assignment in One Statement

* Initialization statement combines declaration and assignment in one single statement (it is just a shortcut, a.k.a. some [“syntactical sugar”](https://en.wikipedia.org/wiki/Syntactic_sugar), and not something new)
* Creates a new variable and also gives it an initial value
* The syntax is the datatype of the variable, the name of the variable, the = sign, the value we want to store, and a semi-colon
* Example: string myName = "Edward";
* Can only be used once per variable, since you can only declare a variable once

### Assignment Details

* Assignment replaces the “old” value of the variable with a “new” one; it is how variables *vary*
  + If you initialize a variable with int myAge = 29; and then write myAge = 30;, the variable myAge now stores the value 30
* You can assign a variable to another variable: just write a variable name on both sides of the = operator
  + This will take a “snapshot” of the current value of the variable on the right side, and store it into the variable on the left side
  + For example, in this code:
  + int a = 12;  
    int b = a;  
    a = -5;
  + the variable b gets the value 12, because that’s the value that a had when the statement int b = a was executed. Even though a was then changed to -5 afterward, b is still 12.

### Displaying

* Only text (strings) can be displayed in the console
* When we want to print a mixture of text and variables with Console.WriteLine, we need to convert all of them to a string
* **String interpolation**: a mechanism for converting a variable’s value to a string and inserting it into the main string
  + Syntax: $"text {variable} text" – begin with a $ symbol, then put variable’s name inside brackets within the string
  + Example: $"I am {myAge} years old"
  + When this line of code is executed, it reads the variable’s current value, converts it to a string (29 becomes "29"), and inserts it into the surrounding string
  + Displayed: I am 29 years old
* If the argument to Console.WriteLine is the name of a variable, it will automatically convert that variable to a string before displaying it
* For example, Console.WriteLine(myAge); will display “29” in the console, as if we had written Console.WriteLine($"{myAge}");
* When string interpolation converts a variable to a string, it must call a “string conversion” method supplied with the data type (int, double, etc.). All built-in C# datatypes come with string conversion methods, but when you write your own data types (classes), you’ll need to write your own string conversions – string interpolation will not magically “know” how to convert MyClass variables to strings

On a final note, observe that you can write statements mixing multiple declarations and assignments, as in int myAge = 10, yourAge, ageDifference; that declares three variables of type int and set the value of the first one. It is generally recommended to separate those instructions in different statements as you begin, to ease debugging and have a better understanding of the “atomic steps” your program should perform.

## Format Specifiers

* Formats for displaying numbers
  + There are lots of possible ways to display a number, especially a fraction (how many decimal places to use?)
  + String interpolation has a default way to format numbers, but it might not always be the best
  + For example, consider this program:
  + decimal price = 19.99m;  
    decimal discount = 0.25m;  
    decimal salePrice = price – discount \* price;  
    Console.WriteLine($"{price} with a discount of " +  
     $"{discount} is {salePrice}");
  + It will display this output:
  + 19.99 with a discount of 0.25 is 14.9925
  + But this isn’t the best way to display prices and discounts. Obviously, the prices should have dollar signs, but also, it does not make sense to show a price with fractional cents (14.9925) – it should be rounded to two decimal places. You might also prefer to display the discount as 25% instead of 0.25, since people usually think of discounts as percentages.
* Improving interpolation with format specifiers
  + You can change how numbers are displayed by adding a format specifier to a variable’s name in string interpolation
  + **Format specifier**: A special letter indicating how a numeric value should be converted to a string
  + General format is {[variable]:[format specifier]}, e.g. {numVar:N}
  + Common format specifiers:

| Format specifier | Description |
| --- | --- |
| N or n | Adds a thousands separator, displays 2 decimal places (by default) |
| E or e | Uses scientific notation, displays 6 decimal places (by default) |
| C or c | Formats as currency: Adds a currency symbol, adds thousands separator, displays 2 decimal places (by default) |
| P or p | Formats as percentage with 2 decimal places (by default) |

* + Example usage with our “discount” program:
  + decimal price = 19.99m;  
    decimal discount = 0.25m;  
    decimal salePrice = price – discount \* price;  
    Console.WriteLine($"{price:C} with a discount of " +  
     $"{discount:P} is {salePrice:C}");
  + will display
  + $19.99 with a discount of 25.00% is $14.99
* Format specifiers with custom rounding
  + Each format specifier uses a default number of decimal places, but you can change this with a precision specifier
  + **Precision specifier**: A number added after a format specifier indicating how many digits past the decimal point to display
  + Format is {[variable]:[format specifier][precision specifier]}, e.g. {numVar:N3}. Note there is no space or other symbol between the format specifier and the precision specifier, and the number can be more than one digit ({numVar:N12} is valid)
  + Examples:
    - Given the declarations
    - double bigNumber = 1537963.666;  
      decimal discount = 0.1337m;

| Statement | Display |
| --- | --- |
| Console.WriteLine($"{bigNumber:N}"); | 1,537,963.67 |
| Console.WriteLine($"{bigNumber:N3}"); | 1,537,963.666 |
| Console.WriteLine($"{bigNumber:N1}"); | 1,537,963.7 |
| Console.WriteLine($"{discount:P1}"); | 13.4% |
| Console.WriteLine($"{discount:P4}"); | 13.3700% |
| Console.WriteLine($"{bigNumber:E}"); | 1.537964E+006 |
| Console.WriteLine($"{bigNumber:E2}"); | 1.54E+006 |

## Variables in Memory

* A variable names a memory location
* Data is stored in memory (RAM), so a variable “stores data” by storing it in memory
* Declaring a variable reserves a memory location (address) and gives it a name
* Assigning to a variable stores data to the memory location (address) named by that variable

### Sizes of Numeric Datatypes

* Numeric datatypes have different sizes
* Amount of memory used/reserved by each variable depends on the variable’s type
* Amount of memory needed for an integer data type depends on the size of the number
  + int uses 4 bytes of memory, can store numbers in the range
  + long uses 8 bytes of memory can store numbers in the range
  + short uses 2 bytes of memory, can store numbers in the range
  + sbyte uses only 1 bytes of memory, can store numbers in the range
* Unsigned versions of the integer types use the same amount of memory, but can store larger positive numbers
  + byte uses 1 byte of memory, can store numbers in the range
  + ushort uses 2 bytes of memory, can store numbers in the range
  + uint uses 4 bytes of memory, can store numbers in the range
  + ulong uses 8 bytes of memory, can store numbers in the range
  + This is because in a signed integer, one bit (digit) of the binary number is needed to represent the sign (+ or -). This means the actual number stored must be 1 bit smaller than the size of the memory (e.g. 31 bits out of the 32 bits in 4 bytes). In an unsigned integer, there is no “sign bit”, so all the bits can be used for the number.
* Amount of memory needed for a floating-point data type depends on the precision (significant figures) of the number
  + float uses 4 bytes of memory, can store positive or negative numbers in a range of approximately , with 7 significant figures of precision
  + double uses 8 bytes of memory, and has both a wider range ( to ) and more significant figures (15 or 16)
  + decimal uses 16 bytes of memory, and has 28 or 29 significant figures of precision, but it actually has the smallest range ( to ) because it stores decimal fractions exactly
* Difference between binary fractions and decimal fractions
  + float and double store their data as binary (base 2) fractions, where each digit represents a power of 2
    - The binary number 101.01 represents , or 5.25 in base 10
  + More specifically, they use binary scientific notation: A mantissa (a binary integer), followed by an exponent assumed to be a power of 2, which is applied to the mantissa
    - 10101e-10 means a mantissa of 10101 (i.e. 21 in base 10) with an exponent of -10 (i.e.  in base 10), which also produces the value 101.01 or 5.25 in base 10
  + Binary fractions cannot represent all base-10 fractions, because they can only represent fractions that are negative powers of 2. is not a negative power of 2 and cannot be represented as a sum of , , , etc.
  + This means some base-10 fractions will get “rounded” to the nearest finite binary fraction, and this will cause errors when they are used in arithmetic
  + On the other hand, decimal stores data as a base-10 fraction, using base-10 scientific notation
  + This is slower for the computer to calculate with (since computers work only in binary) but has no “rounding errors” with fractions that include 0.1
  + Use decimal when working with money (since money uses a lot of 0.1 and 0.01 fractions), double when working with non-money fractions

**Summary of numeric data types and sizes:**

| Type | Size | Range of Values | Precision |
| --- | --- | --- | --- |
| sbyte | 1 bytes |  | N/A |
| byte | 1 bytes |  | N/A |
| short | 2 bytes |  | N/A |
| ushort | 2 bytes |  | N/A |
| int | 4 bytes |  | N/A |
| uint | 4 bytes |  | N/A |
| long | 8 bytes |  | N/A |
| ulong | 8 bytes |  | N/A |
| float | 4 bytes |  | 7 digits |
| double | 8 bytes |  | 15-16 digits |
| decimal | 16 bytes |  | 28-29 digits |

### Value and Reference types

* Value and reference types are different ways of storing data in memory
* Variables name memory locations, but the data that gets stored at the named location is different for each type
* For a **value type** variable, the named memory location stores the exact data value held by the variable (just what you’d expect)
* Value types: all the numeric types (int, float, double, decimal, etc.), char, and bool
* For a **reference type** variable, the named memory location stores a *reference* to the data, not the data itself
  + The contents of the memory location named by the variable are the address of another memory location
  + The *other* memory location is where the variable’s data is stored
  + To get to the data, the computer first reads the location named by the variable, then uses that information (the memory address) to find and read the other memory location where the data is stored
* Reference types: string, object, and all objects you create from your own classes
* Assignment works differently for reference types
  + Assignment always copies the value in the variable’s named memory location - but in the case of a reference type that’s just a memory address, not the data
  + Assigning one reference-type variable to another copies the memory address, so now both variables “refer to” the same data
  + Example:
  + string word = "Hello";  
    string word2 = word;
  + Both word and word2 contain the same memory address, pointing to the same memory location, which contains the string “Hello”. There is only one copy of the string “Hello”; word2 does not get its own copy.

# Operators

## Arithmetic Operators

Variables can be used to do math. All the usual arithmetic operations are available in C#:

| Operation | C# Operator | C# Expression |
| --- | --- | --- |
| Addition | + | myVar + 7 |
| Subtraction | - | myVar - 7 |
| Multiplication | \* | myVar \* 7 |
| Division | / | myVar / 7 |
| Remainder (a.k.a. modulo) | % | myVar % 7 |

Note: the “remainder” or “modulo” operator represents the remainder after doing integer division between its two operands.  
For example, 44 % 7 = 2 because 44/7 = 6 when rounded down, then do 7\*6 to get 42 and 44 - 42 = 2.

## Arithmetic and variables

* The result of an arithmetic expression (like those shown in the table) is a numeric value
  + For example, the C# expression 3 \* 4 has the value 12, which is int data
* A numeric value can be assigned to a variable of the same type, just like a literal: int myVar = 3 \* 4; initializes the variable myVar to contain the value 12
* A numeric-type variable can be used in an arithmetic expression
* When a variable is used in an arithmetic expression, its current value is read, and the math is done on that value
* Example:
* int a = 4;  
  int b = a + 5;  
  a = b \* 2;
  + To execute the second line of the code, the computer will first evaluate the expression on the right side of the = sign. It reads the value of the variable a, which is 4, and then computes the result of 4 + 5, which is 9. Then, it assigns this value to the variable b (remember assignment goes right to left).
  + To execute the third line of code, the computer first evaluates the expression on the right side of the = sign, which means reading the value of b to use in the arithmetic operation. b contains 9, so the expression is 9 \* 2, which evaluates to 18. Then it assigns the value 18 to the variable a, which now contains 18 instead of
* A variable can appear on both sides of the = sign, like this:
* int myVar = 4;  
  myVar = myVar \* 2;
* This looks like a paradox because myVar is assigned to itself, but it has a clear meaning because assignment is evaluated right to left. When executing the second line of code, the computer evaluates the right side of the = before doing the assignment. So it first reads the current (“old”) value of myVar, which is 4, and computes 4 \* 2 to get the value 8. Then, it assigns the new value to myVar, overwriting its old value.

## Compound assignment operators

* The pattern of “compute an expression with a variable, then assign the result to that variable” is common, so there are shortcuts for doing it
* The **compound assignment operators** change the value of a variable by adding, subtracting, etc. from its current value, equivalent to an assignment statement that has the value on both sides:

| Statement | Equivalent |
| --- | --- |
| x += 2; | x = x + 2; |
| x -= 2; | x = x - 2; |
| x \*= 2; | x = x \* 2; |
| x /= 2; | x = x / 2; |
| x %= 2; | x = x % 2; |

## Increment and Decrement Operators

### Increment and decrement basics

* In C#, we have already seen multiple ways to add 1 to a numeric variable:

int myVar = 1;  
myVar = myVar + 1;  
myVar += 1

These two lines of code have the same effect; the += operator is “shorthand” for “add and assign”

* The **increment operator**, ++, is an even shorter way to add 1 to a variable. It can be used in two ways:

myVar++;  
++myVar;

* Writing ++ after the name of the variable is called a **postfix increment**, while writing ++ before the name of the variable is called a **prefix increment**. They both have the same effect on the variable: its value increases by 1.
* Similarly, there are multiple ways to subtract 1 from a numeric variable:

int myVar = 10;  
myVar = myVar - 1;  
myVar -= 1;

* The **decrement operator**, --, is a shortcut for subtracting 1 from a variable, and is used just like the increment operator:

myVar--;  
--myVar;

* To summarize, the increment and decrement operators both have a prefix and postfix version:

|  | Increment | Decrement |
| --- | --- | --- |
| Postfix | myVar++ | myVar-- |
| Prefix | ++myVar | --myVar |

### Difference between prefix and postfix

* The prefix and postfix versions of the increment and decrement operators both have the same effect on the variable: Its value increases or decreases by 1
* The difference between prefix and postfix is whether the “old” or “new” value of the variable is *returned* by the expression
* With postfix increment/decrement, the operator returns the value of the variable, *then* increases/decreases it by 1
* This means the value of the increment/decrement expression is the *old* value of the variable, before it was incremented/decremented
* Consider this example:

int a = 1;  
Console.WriteLine(a++);  
Console.WriteLine(a--);

* The expression a++ returns the current value of a, which is 1, to be used in Console.WriteLine. *Then* it increments a by 1, giving it a new value of 2. Thus, the first Console.WriteLine displays “1” on the screen.
* The expression a-- returns the current value of a, which is 2, to be used in Console.WriteLine, and *then* decrements a by 1. Thus, the second Console.WriteLine displays “2” on the screen.
* With prefix increment/decrement, the operator increases/decreases the value of the variable by 1, *then* returns its value
* This means the value of the increment/decrement expression is the *new* value of the variable, after the increment/decrement
* Consider the same code, but with prefix instead of postfix operators:

int a = 1;  
Console.WriteLine(++a);  
Console.WriteLine(--a);

* The expression ++a increments a by 1, then returns the value of a for use in Console.WriteLine. Thus, the first Console.WriteLine displays “2” on the screen.
* The expression --a decrements a by 1, then returns the value of a for use in Console.WriteLine. Thus, the second Console.WriteLine displays “1” on the screen.

### Using increment/decrement in expressions

* The ++ and -- operators have higher precedence than the other math operators, so if you use them in an expression they will get executed first
* The “result” of the operator, i.e. the value that will be used in the rest of the math expression, depends on whether it is the prefix or postfix increment/decrement operator: The prefix operator returns the variable’s new value, while the postfix operator returns the variable’s old value
* Consider these examples:

int a = 1;  
int b = a++;  
int c = ++a \* 2 + 4;  
int d = a-- + 1;

* The variable b gets the value 1, because a++ returns the “old” value of a (1) and then increments a to 2
* In the expression ++a \* 2 + 4, the operator ++a executes first, and it returns the new value of a, which is 3. Then the multiplication executes (3 \* 2, which is 6), then the addition (6 + 4, which is 10). Thus c gets the value 10.
* In thee expression a-- + 1, the operator a-- executes first, and it returns the *old* value of a, which is 3 (even though a is now 2). Then the addition executes, so d gets the value 4.

## Arithmetic on Mixed Data Types

* The math operators (+, -, \*, /) are defined separately for each data type: There is an int version of + that adds ints, a float version of + that adds floats, etc.
* Each operator expects to get two values of the same type on each side, and produces a result of that same type. For example, 2.25 + 3.25 uses the double version of +, which adds the two double values to produce a double-type result, 5.5.
* Most operators have the same effect regardless of their type, except for /
* The int/short/long version of / does **integer division**, which returns only the quotient and drops the remainder: In the statement int result = 21 / 5;, the variable result gets the value 4, because is 4 with a remainder of 1. If you want the fractional part, you need to use the floating-point version (for float, double, and decimal): double fracDiv = 21.0 / 5.0; will initialize fracDiv to 4.2.

### Implicit conversions in math

* If the two operands/arguments to a math operator are not the same type, they must become the same type – one must be converted
* C# will first try implicit conversion to “promote” a less-precise or smaller value to a more precise, larger type
* Example: with the expression double fracDiv = 21 / 2.4;
  + Operand types are int and double
  + int is smaller/less-precise than double
  + 21 gets implicitly converted to 21.0, a double value
  + Now the operands are both double type, so the double version of the / operator gets executed
  + The result is 8.75, a double value, which gets assigned to the variable fracDiv
* Implicit conversion also happens in assignment statements, which happen *after* the math expression is computed
* Example: with the expression double fraction = 21 / 5;
  + Operand types are int and int
  + Since they match, the int version of / gets executed
  + The result is 4, an int value
  + Now this value is assigned to the variable fraction, which is double type
  + The int value is implicitly converted to the double value 4.0, and fraction is assigned the value 4.0

### Explicit conversions in math

* If the operands are int type, the int version of / will get called, even if you assign the result to a double
* You can “force” floating-point division by explicitly converting one operand to double or float
* Example:
* int numCookies = 21;  
  int numPeople = 6;  
  double share = (double) numCookies / numPeople;
* Without the cast, share would get the value 3.0 because numCookies and numPeople are both int type (just like the fraction example above). With the cast, numCookies is converted to the value 21.0 (a double), which means the operands are no longer the same type. This will cause numPeople to be implicitly converted to double in order to make them match, and the double version of / will get called to evaluate 21.0 / 6.0. The result is 3.5, so share gets assigned 3.5.
* You might also *need* a cast to ensure the operands are the same type, if implicit conversion does not work
* Example:
* decimal price = 3.89;  
  double shares = 47.75;  
  decimal total = price \* (decimal) shares;
* In this code, double cannot be implicitly converted to decimal, and decimal cannot be implicitly converted to double, so the multiplication price \* shares would produce a compile error. We need an explicit cast to decimal to make both operands the same type (decimal).

## Order of Operations

* Math operations in C# follow PEMDAS from math class: Parentheses, Exponents, Multiplication, Division, Addition, Subtraction
  + Multiplication/division are evaluated together, as are addition/subtraction
  + Expressions are evaluated left-to-right
  + Example: int x = 4 = 10 \* 3 - 21 / 2 - (3 + 3);
    - Parentheses: (3 + 3) is evaluated, returns 6
    - Multiplication/Division: 10 \* 3 is evaluated to produce 30, then 21 / 2 is evaluated to produce 10 (left-to-right)
    - Addition/Subtraction: 4 + 30 - 10 - 6 is evaluated, result is 18
* Cast operator is higher priority than all binary operators
  + Example: double share = (double) numCookies / numPeople;
    - Cast operator is evaluated first, converts numCookies to a double
    - Division is evaluated next, but operand types do not match
    - numPeople is implicitly converted to double to make operand types match
    - Then division is evaluated, result is 21.0 / 6.0 = 3.5
* Parentheses always increase priority, even with casts
  + An expression in parentheses gets evaluated before the cast “next to” it
  + Example:
  + int a = 5, b = 4;  
    double result = (double) (a / b);
  + The expression in parentheses gets evaluated first, then the result has the (double) cast applied to it. That means a / b is evaluated to produce 1, since a and b are both int type, and then that result is cast to a double, producing 1.0.

# Conversions

We now discuss implicit and explicit conversions between datatypes: how C# can (or not!) convert a value from one datatype to another, and how we can “force” this conversion if C# does not do it automatically.

### Assignments from different types

* The “proper” way to initialize a variable is to assign it a literal of the same type:

int myAge = 29;  
double myHeight = 1.77;  
float radius = 2.3f;

Note that 1.77 is a double literal, while 2.3f is a float literal

* If the literal is not the same type as the variable, you will sometimes get an error – for example, float radius = 2.3 will result in a compile error – but sometimes, it appears to work fine: for example float radius = 2; compiles and executes without error even though 2 is an int value.
* In fact, the value being assigned to the variable **must** be the same type as the variable, but some types can be **implicitly converted** to others

### Implicit conversions

* Implicit conversion allows variables to be assigned from literals of the “wrong” type: the literal value is first implicitly converted to the right type
* In the statement float radius = 2;, the int value 2 is implicitly converted to an equivalent float value, 2.0f. Then the computer assigns 2.0f to the radius variable.
* Implicit conversion also allows variables to be assigned from other variables that have a different type:

int length = 2;  
float radius = length;

When the computer executes the second line of this code, it reads the variable length to get an int value 2. It then implicitly converts that value to 2.0f, and then assigns 2.0f to the float-type variable radius.

* Implicit conversion only works between *some* data types: a value will only be implicitly converted if it is “safe” to do so without losing data
* Summary of possible implicit conversions:

| Type | Possible Implicit Conversions |
| --- | --- |
| short | int, long, float, double, decimal |
| int | long, float, double, decimal |
| long | float, double, decimal |
| ushort | uint, int, ulong, long, decimal, float, double |
| uint | ulong, long, decimal, float, double |
| ulong | decimal, float, double |
| float | double |

* In general, a data type can only be implicitly converted to one with a *larger range* of possible values
* Since an int can store any integer between and , but a float can store any integer between and (as well as fractional values), it is always safe to store an int value in a float
* You *cannot* implicitly convert a float to an int because an int stores fewer values than a float – it cannot store fractions – so converting a float to an int will **lose data**
* Note that all integer data types can be implicitly converted to float or double
* Each integer data type can be implicitly converted to a larger integer type: short int long
* Unsigned integer data types can be implicitly converted to a *larger* signed integer type, but not the *same* signed integer type: uint long, but **not** uint int
* This is because of the “sign bit”: a uint can store larger values than an int because it does not use a sign bit, so converting a large uint to an int might lose data

### Explicit conversions

* Any conversion that is “unsafe” because it might lose data will not happen automatically: you get a compile error if you assign a double variable to a float variable
* If you want to do an unsafe conversion anyway, you must perform an **explicit conversion** with the **cast operator**
* Cast operator syntax: ([type name]) [variable or value] – the cast is “right-associative”, so it applies to the variable to the right of the type name
* Example: (float) 2.8 or (int) radius
* Explicit conversions are often used when you (the programmer) know the conversion is actually “safe” – data will not actually be lost
* For example, in this code, we know that 2.886 is within the range of a float, so it is safe to convert it to a float:

float radius = (float) 2.886;

The variable radius will be assigned the value 2.886f.

* For example, in this code, we know that 2.0 is safe to convert to an int because it has no fractional part:

double length = 2.0;  
int height = (int) length;

The variable height will be assigned the value 2.

* Explicit conversions only work if there exists code to perform the conversion, usually in the standard library. The cast operator isn’t “magic” – it just calls a method that is defined to convert one type of data (e.g. double) to another (e.g. int).
* All the C# numeric types have explicit conversions to each other defined
* string does not have explicit conversions defined, so you cannot write int myAge = (int) "29";
* If the explicit conversion is truly unsafe (will lose data), data is lost in a specific way
* Casting from floating-point (e.g. double) types to integer types: fractional part of number is *truncated* (ignored/dropped)
* In int length = (int) 2.886;, the value 2.886 is truncated to 2 by the cast to int, so the variable length gets the value 2.
* Casting from more-precise to less-precise floating point type: number is *rounded* to nearest value that fits in less-precise type:

decimal myDecimal = 123456789.999999918m;  
double myDouble = (double) myDecimal;  
float myFloat = (float) myDouble;

In this code, myDouble gets the value 123456789.99999993, while myFloat gets the value 123456790.0f, as the original decimal value is rounded to fit types with fewer significant figures of precision.

* Casting from a larger integer to a smaller integer: the most significant *bits* are truncated – remember that numbers are stored in binary format
* This can cause weird results, since the least-significant *bits* of a number in binary do not correspond to the least significant *digits* of the equivalent base-10 number
* Casting from another floating point type to decimal: Either value is stored precisely (no rounding), or *program crashes* with System.OverflowException if value is larger than decimal’s maximum value:

decimal fromSmall = (decimal) 42.76875;  
double bigDouble = 2.65e35;  
decimal fromBig = (decimal) bigDouble;

In this code, fromSmall will get the value 42.76875m, but the program will crash when attempting to cast bigDouble to a decimal because is larger than decimal’s maximum value of

* decimal is more precise than the other two floating-point types (thus does not need to round), but has a smaller range (only , vs. )

Summary of implicit and explicit conversions for the numeric datatypes:

“Implicit and Explicit Conversion Between Datatypes”

Refer to [the “Result Type of Operations” chart from the cheatsheet](https:/princomp.github.io/docs/programming_and_computer_usage/datatypes_in_csharp) for more detail.

# Inputs and Outputs

## Reading Input from the User

* Input and output in CLI
  + Our programs use a command-line interface, where input and output come from text printed in a “terminal” or “console”
  + We’ve already seen that Console.WriteLine prints text from your program on the screen to provide output to the user
  + The equivalent method for reading input is Console.ReadLine(), which waits for the user to type some text in the console and then returns it to your program
  + In general, the Console class represents the command-line interface
* Using Console.ReadLine()
  + Example usage:
  + using System;  
      
    class PersonalizedWelcomeMessage  
    {  
     static void Main()  
     {  
     string firstName;  
     Console.WriteLine("Enter your first name:");  
     firstName = Console.ReadLine();  
     Console.WriteLine($"Welcome, {firstName}!");  
     }  
    }
  + This program first declares a string variable named firstName. On the second line, it uses Console.WriteLine to display a message (instructions for the user). On the third line, it calls the Console.ReadLine() method, and assigns its return value (result) to the firstName variable. This means the program waits for the user to type some text and press “Enter”, and then stores that text in firstName. Finally, the program uses string interpolation in Console.WriteLine to display a message including the contents of the firstName variable.
  + Console.ReadLine is the “inverse” of Console.WriteLine, and the way you use it is also the “inverse”
  + While Console.WriteLine takes an argument, which is the text you want to display on the screen, Console.ReadLine() takes no arguments because it does not need any input from your program – it will always do the same thing
  + Console.WriteLine has no “return value” - it does not give any output back to your program, and the only effect of calling it is that text is displayed on the screen
  + Console.ReadLine() does have a return value, specifically a string. This means you can use the result of this method to assign a string variable, just like you can use the result of an arithmetic expression to assign a numeric variable.
  + The string that Console.ReadLine() returns is **one line of text** typed in the console. When you call it, the computer will wait for the user to type some text and then press “Enter”, and everything the user typed before pressing “Enter” gets returned from Console.ReadLine()

### Parsing user input

* Console.ReadLine() always returns the same type of data, a string, regardless of what the user enters
  + If you ask the user to enter a number, ReadLine will output that number as a string
  + For example, if you ask the user to enter his/her age, and the user enters 21, Console.ReadLine() will return the string "21"
* If we want to do any kind of arithmetic with a number provided by the user, we will need to convert that string to a numeric type like int or double. Remember that casting cannot be used to convert numeric data *to or from* string data.
* When converting numeric data to string data, we use string interpolation:
* int myAge = 29;  
  //This does not work:  
  //string strAge = (string) myAge;  
  string strAge = $"{myAge}";
* In the other direction, we use a method called Parse to convert strings to numbers:
* string strAge = "29";  
  //This does not work:  
  //int myAge = (int) strAge;  
  int myAge = int.Parse(strAge);
* The int.Parse method takes a string as an argument, and returns an int containing the numeric value written in that string
* Each built-in numeric type has its own Parse method
  + int.Parse("42") returns the value 42
  + long.Parse("42") returns the value 42L
  + double.Parse("3.65") returns the value 3.65
  + float.Parse("3.65") returns the value 3.65f
  + decimal.Parse("3.65") returns the value 3.65m
* The Parse methods are useful for converting user input to useable data. For example, this is how to get the user’s age as an int:
* Console.WriteLine("Enter your age:");  
  string ageString = Console.ReadLine();  
  int age = int.Parse(ageString);

### More detail on the Parse methods

* Console.WriteLine is a method that takes input from your program, in the form of an argument, but does not return any output. Meanwhile, Console.ReadLine is a method that does not have any arguments, but it returns output to your program (the user’s string).
* int.Parse is a method that both takes input (the string argument) and returns output (the converted int value)
* When executing a statement such as
* int answer = int.Parse("42");
* the computer must evaluate the expression on the right side of the = operator before it can do the assignment. This means it calls the int.Parse method with the string "42" as input. The method’s code then executes, converting "42" to an integer, and it returns a result, the int value 42. This value can now be assigned to the variable answer.
* Since the return value of a Parse method is a numeric type, it can be used in arithmetic expressions just like a numeric-type variable or literal. For example, in this statement:
* double result = double.Parse("3.65") \* 4;
* To evaluate the expression on the right side of the = operator, the computer must first call the method double.Parse with the input "3.65". Then the method’s return value, 3.65, is used the math operation as if it was written 3.65 \* 4. So the computer implicitly converts 4 to a double value, performs the multiplication on doubles, and gets the resulting value 14.6, which it assigns to the variable result.
* Another example of using the result of Parse to do math:
* Console.WriteLine("Please enter the year.");  
  string userInput = Console.ReadLine();  
  int curYear = int.Parse(userInput);  
  Console.WriteLine($"Next year it will be {curYear + 1}");
* Note that in order to do arithmetic with the user’s input (i.e. add 1), it must be a numeric type (i.e. int), not a string. This is why we often call a Parse method on the data returned by Console.ReadLine().
* The previous example can be made shorter and simpler by combining the Parse and ReadLine methods in one statement. Specifically, you can write:
* int curYear = int.Parse(Console.ReadLine());
* In this statement, the return value (output) of one method is used as the argument (input) to another method. When the computer executes the statement, it starts by evaluating the int.Parse(...) method call, but it cannot actually execute the Parse method yet because its argument is an expression, not a variable or value. In order to determine what value to send to the Parse method as input, it must first evaluate the Console.ReadLine() method call. Since this method has no arguments, the computer can immediately start executing it; the ReadLine method waits for the user to type a line of text, then returns that text as a string value. This return value can now be used as the argument to int.Parse, and the computer starts executing int.Parse with the user-provided string as input. When the Parse method returns an int value, this value becomes the value of the entire expression int.Parse(Console.ReadLine()), and the computer assigns it to the variable curYear.
* Notice that by placing the call to ReadLine inside the argument to Parse, we have eliminated the variable userInput entirely. The string returned by ReadLine does not need to be stored anywhere (i.e. in a variable); it only needs to exist long enough to be sent to the Parse method as input.

### Correct input formatting

* The Parse methods *assume* that the string they are given as an argument (i.e. the user input) actually contains a valid number. But the user may not follow directions, and invalid input can cause a variety of errors.
* If the string does not contain a number at all – e.g. int badIdea = int.Parse("Hello"); – the program will fail with the error System.FormatException
* If the string contains a number with a decimal point, but the Parse method is for an integer datatype, the program will also fail with System.FormatException. For example, int fromFraction = int.Parse("52.5"); will cause this error. This will happen even if the number in the string ends in “.0” (meaning it has no fractional part), such as int wholeNumber = int.Parse("45.0");.
* If the string has extraneous text before or after the number, such as "$18.95" or 1999!, the program will fail with the error System.FormatException
* If the string contains a number that cannot fit in the desired datatype (due to overflow or underflow), the behavior depends on the datatype:
  + For the integer types (int and long), the program will fail with the error System.OverflowException. For example, int.Parse("3000000000") will cause this error because 3000000000 is larger than (the maximum value an int can store).
  + For the floating-point types (float and double), no error will be produced. Instead, the result will be the same as if an overflow or underflow had occurred during normal program execution: an overflow will produce the value Infinity, and an underflow will produce the value 0. For example, float tooSmall = float.Parse("1.5e-55"); will assign tooSmall the value 0, while double tooBig = double.Parse("1.8e310"); will assign tooBig the value double.Infinity.
* Acceptable string formats vary slightly between the numeric types, due to the different ranges of values they can contain
  + int.Parse and long.Parse will accept strings in the format ([ws])([sign])[digits]([ws]), where [ws] represents empty spaces and groups in parentheses are **optional**. This means that a string with leading or trailing spaces will not cause an error, unlike a string with other extraneous text around the number.
  + decimal.Parse will accept strings in the format ([ws])([sign])([digits],)[digits](.[digits])([ws]). Note that you can optionally include commas between groups of digits, and the decimal point is also optional. This means a string like "18,999" is valid for decimal.Parse but not for int.Parse.
  + float.Parse and double.Parse will accept strings in the format ([ws])([sign])([digits],)[digits](.[digits])(e[sign][digits])([ws]). As with decimal, you can include commas between groups of digits. In addition, you can write the string in scientific notation with the letter “e” or “E” followed by an exponent, such as "-9.44e15".

## Output with Variables

### Converting from numbers to strings

* As we saw in a previous lecture (Datatypes and Variables), the Console.WriteLine method needs a string as its argument
* If the variable you want to display is not a string, you might think you could cast it to a string, but that will not work – there is no explicit conversion from string to numeric types
  + This code:
  + double fraction = (double) 47 / 6;  
    string text = (string) fraction;
  + will produce a compile error
* You *can* convert numeric data to a string using string interpolation, which we’ve used before in Console.WriteLine statements:
* int x = 47, y = 6;  
  double fraction = (double) x / y;  
  string text = $"{x} divided by {y} is {fraction}";
* After executing this code, text will contain “47 divided by 6 is 7.8333333”
* String interpolation can convert any expression to a string, not just a single variable. For example, you can write:
* Console.WriteLine($"{x} divided by {y} is {(double) x / y}");  
  Console.WriteLine($"{x} plus 7 is {x + 7}");
* This will display the following output:
* 47 divided by 6 is 7.8333333  
  47 plus 7 is 54
* Note that writing a math expression inside a string interpolation statement does not change the values of any variables. After executing this code, x is still 47, and y is still 6.

### The ToString() method

* String interpolation does not “magically know” how to convert numbers to strings – it delegates the task to the numbers themselves
* This works because all data types in C# are objects, even the built-in ones like int and double
  + Since they are objects, they can have methods
* **All** objects in C# are guaranteed to have a method named ToString(), whose return value (result) is a string
* Meaning of ToString() method: “Convert this object to a string, and return that string”
* This means you can call the ToString() method on any variable to convert it to a string, like this:
* int num = 42;  
  double fraction = 33.5;  
  string intText = num.ToString();  
  string fracText = fraction.ToString();
* After executing this code, intText will contain the string “42”, and fracText will contain the string “33.5”
* String interpolation calls ToString() on each variable or expression within braces, asking it to convert itself to a string
  + In other words, these three statements are all the same:
  + Console.WriteLine($"num is {num}");  
    Console.WriteLine($"num is {intText}");  
    Console.WriteLine($"num is {num.ToString()}");
  + Putting num within the braces is the same as calling ToString() on it.

## String Concatenation

* Now that we’ve seen ToString(), we can introduce another operator: the concatenation operator
* Concatenation basics
  + Remember, the + operator is defined separately for each data type. The “double + double” operator is different from the “int + int” operator.
  + If the operand types are string (i.e. string + string), the + operator performs concatenation, not addition
  + You can concatenate string literals or string variables:
  + string greeting = "Hi there, " + "John";  
    string name = "Paul";  
    string greeting2 = "Hi there, " + name;
  + After executing this code, greeting will contain “Hi there, John” and greeting2 will contain “Hi there, Paul”
* Concatenation with mixed types
  + Just like with the other operators, both operands (both sides of the +) must be the same type
  + If one operand is a string and the other is not a string, the ToString() method will automatically be called to convert it to a string
  + Example: In this code:
  + int bananas = 42;  
    string text = "Bananas: " + bananas;
  + The + operator has a string operand and an int operand, so the int will be converted to a string. This means the computer will call bananas.ToString(), which returns the string “42”. Then the string + string operator is called with the operands “Bananas:” and “42”, which concatenates them into “Bananas: 42”.

### Output with concatenation

* We now have two different ways to construct a string for Console.WriteLine: Interpolation and concatenation
* Concatenating a string with a variable will automatically call its ToString() method, just like interpolation will. These two WriteLine calls are equivalent:
* int num = 42;  
  Console.WriteLine($"num is {num}");  
  Console.WriteLine("num is " + num);
* It’s usually easier to use interpolation, since when you have many variables the + signs start to add up. Compare the length of these two equivalent lines of code:
* Console.WriteLine($"The variables are {a}, {b}, {c}, {d}, and {e}");  
  Console.WriteLine("The variables are " + a + ", " + b + ", " + c + ", " + d + ", and " + e);
* Be careful when using concatenation with numeric variables: the meaning of + depends on the types of its two operands
  + If both operands are numbers, the + operator does addition
  + If both operands are strings, the + operator does concatenation
  + If *one* argument is a string, the other argument will be converted to a string using ToString()
  + Expressions in C# are always evaluated **left-to-right**, just like arithmetic
  + Therefore, in this code:
  + int var1 = 6, var2 = 7;  
    Console.WriteLine(var1 + var2 + " is the result");  
    Console.WriteLine("The result is " + var1 + var2);
  + The first WriteLine will display “13 is the result”, because var1 and var2 are both ints, so the first + operator performs addition on two ints (the resulting number,13, is then converted to a string for the second + operator). However, the second WriteLine will display “The result is 67”, because both + operators perform concatenation: The first one concatenates a string with var1 to produce a string, and then the second one concatenates this string with var2
  + If you want to combine addition and concatenation in the same line of code, use parentheses to make the order and grouping of operations explicit. For example:
  + int var1 = 6, var2 = 7;  
    Console.WriteLine((var1 + var2) + " is the result");  
    Console.WriteLine("The result is " + (var1 + var2));
  + In this code, the parentheses ensure that var1 + var2 is always interpreted as addition.

# Introduction

## Class and Object Basics

* Classes vs. Objects
  + A **class** is a specification, blueprint, or template for an object; it is the code that describes what data the object stores and what it can do
  + An **object** is a single instance of a class, created using its “template.” It is executing code, with specific values stored in each variable
  + To **instantiate** an object is to create a new object from a class
* Object design basics
  + Objects have **attributes**: data stored in the object. This data is different in each instance, although the type of data is defined in the class.
  + Objects have **methods**: functions that use or modify the object’s data. The code for these functions is defined in the class, but it is executed on (and modifies) a specific object
* Encapsulation: An important principle in class/object design
  + Attribute data is stored in **instance variables**, a special kind of variable
  + Called “instance” because each instance, i.e. object, has its own copy of them
  + **Encapsulation** means instance variables (attributes) are “hidden” inside an object: other code cannot access them directly
    - Only the object’s own methods can access the instance variables
    - Other code must “ask permission” from the object in order to read or write the variables

## Writing Our First Class

* Designing the class
  + Our first class will be used to represent rectangles; each instance (object) will represent one rectangle
  + Attributes of a rectangle:
    - Length
    - Width
  + Methods that will use the rectangle’s attributes
    - Get length
    - Get width
    - Set length
    - Set width
    - Compute the rectangle’s area
  + Note that the first four are a specific type of method called “getters” and “setters” because they allow other code to read (get) or write (set) the rectangle’s instance variables while respecting encapsulation

The Rectangle class:

class Rectangle  
{  
 private int length;  
 private int width;  
  
 public void SetLength(int lengthParameter)  
 {  
 length = lengthParameter;  
 }  
  
 public int GetLength()  
 {  
 return length;  
 }  
  
 public void SetWidth(int widthParameter)  
 {  
 width = widthParameter;  
 }  
  
 public int GetWidth()  
 {  
 return width;  
 }  
  
 public int ComputeArea()  
 {  
 return length \* width;  
 }  
}

Let’s look at each part of this code in order.

* Attributes
  + Each attribute (length and width) is stored in an instance variable
  + Instance variables are declared similarly to “regular” variables, but with one additional feature: the **access modifier**
  + Syntax: [access modifier] [type] [variable name]
  + The access modifier can have several values, the most common of which are public and private. (There are other access modifiers, such as protected and internal, but in this class we will only be using public and private).
  + An access modifier of private is what enforces encapsulation: when you use this access modifier, it means the instance variable cannot be accessed by any code outside the Rectangle class
  + The C# compiler will give you an error if you write code that attempts to use a private instance variable anywhere other than a method of that variable’s class
* SetLength method, an example of a “setter” method
  + This method will allow code outside the Rectangle class to modify a Rectangle object’s “length” attribute
  + Note that the header of this method has an access modifier, just like the instance variable
  + In this case the access modifier is public because we *want* to allow other code to call the SetLength method
  + Syntax of a method declaration: [access modifier] [return type] [method name]([parameters])
  + This method has one **parameter**, named lengthParameter, whose type is int. This means the method must be called with one **argument** that is int type.
    - Similar to how Console.WriteLine must be called with one argument that is string type – the Console.WriteLine declaration has one parameter that is string type.
    - Note that it is declared just like a variable, with a type and a name
  + A parameter works like a variable: it has a type and a value, and you can use it in expressions and assignment
  + When you call a method with a particular argument, like 15, the parameter is assigned this value, so within the method’s code you can assume the parameter value is “the argument to this method”
  + The body of the SetLength method has one statement, which assigns the instance variable length to the value contained in the parameter lengthParameter. In other words, whatever argument SetLength is called with will get assigned to length
  + This is why it is called a “setter”: SetLength(15) will set length to 15.
* GetLength method, an example of a “getter” method
  + This method will allow code outside the Rectangle class to read the current value of a Rectangle object’s “length” attribute
  + The **return type** of this method is int, which means that the value it returns to the calling code is an int value
  + Recall that Console.ReadLine() returns a string value to the caller, which is why you can write string userInput = Console.ReadLine(). The GetLength method will do the same thing, only with an int instead of a string
  + This method has no parameters, so you do not provide any arguments when calling it. “Getter” methods never have parameters, since their purpose is to “get” (read) a value, not change anything
  + The body of GetLength has one statement, which uses a new keyword: return. This keyword declares what will be returned by the method, i.e. what particular value will be given to the caller to use in an expression.
  + In a “getter” method, the value we return is the instance variable that corresponds to the attribute named in the method. GetLength returns the length instance variable.
* SetWidth method
  + This is another “setter” method, so it looks very similar to SetLength
  + It takes one parameter (widthParameter) and assigns it to the width instance variable
  + Note that the return type of both setters is void. The return type void means “this method does not return a value.” Console.WriteLine is an example of a void method we’ve used already.
  + Since the return type is void, there is no return statement in this method
* GetWidth method
  + This is the “getter” method for the width attribute
  + It looks very similar to GetLength, except the instance variable in the return statement is width rather than length
* The ComputeArea method
  + This is *not* a getter or setter: its goal is not to read or write a single instance variable
  + The goal of this method is to compute and return the rectangle’s area
  + Since the area of the rectangle will be an int (it is the product of two ints), we declare the return type of the method to be int
  + This method has no parameters, because it does not need any arguments. Its only “input” is the instance variables, and it will always do the same thing every time you call it.
  + The body of the method has a return statement with an expression, rather than a single variable
  + When you write return [expression], the expression will be evaluated first, then the resulting value will be used by the return command
  + In this case, the expression length \* width will be evaluated, which computes the area of the rectangle. Since both length and width are ints, the int version of the \* operator executes, and it produces an int result. This resulting int is what the method returns.

## Using Our Class

* We’ve written a class, but it does not do anything yet
  + The class is a blueprint for an object, not an object
  + To make it “do something” (i.e. execute some methods), we need to instantiate an object using this class
  + The code that does this should be in a separate file (e.g. Program.cs), not in Rectangle.cs
* Here is a program that uses our Rectangle class:

using System;  
  
class Program  
{  
 static void Main(string[] args)  
 {  
 Rectangle myRectangle = new Rectangle();  
 myRectangle.SetLength(12);  
 myRectangle.SetWidth(3);  
 int area = myRectangle.ComputeArea();  
 Console.WriteLine(  
 "Your rectangle's length is "  
 + $"{myRectangle.GetLength()}, and its width is "  
 + $"{myRectangle.GetWidth()}, so its area is {area}."  
 );  
 }  
}

* Instantiating an object
  + The first line of code creates a Rectangle object
  + The left side of the = sign is a variable declaration – it declares a variable of type Rectangle
    - Classes we write become new data types in C#
  + The right side of the = sign assigns this variable a value: a Rectangle object
  + We **instantiate** an object by writing the keyword new followed by the name of the class (syntax: new [class name]()). The empty parentheses are required, but we will explain why later.
  + This statement is really an initialization statement: It declares and assigns a variable in one line
  + The value of the myRectangle variable is the Rectangle object that was created by new Rectangle()
* Calling setters on the object
  + The next two lines of code call the SetLength and SetWidth methods on the object
  + Syntax: [object name].[method name]([argument]). Note the “dot operator” between the variable name and the method name.
  + SetLength is called with an argument of 12, so lengthParameter gets the value 12, and the rectangle’s length instance variable is then assigned this value
  + Similarly, SetWidth is called with an argument of 3, so the rectangle’s width instance variable is assigned the value 3
* Calling ComputeArea
  + The next line calls the ComputeArea method and assigns its result to a new variable named area
  + The syntax is the same as the other method calls
  + Since this method has a return value, we need to do something with the return value – we assign it to a variable
  + Similar to how you must do something with the result (return value) of Console.ReadLine(), i.e. string userInput = Console.ReadLine()
* Calling getters on the object
  + The last line of code displays some information about the rectangle object using string interpolation
  + One part of the string interpolation is the area variable, which we’ve seen before
  + The other interpolated values are myRectangle.GetLength() and myRectangle.GetWidth()
  + Looking at the first one: this will call the GetLength method, which has a return value that is an int. Instead of storing the return value in an int variable, we put it in the string interpolation brackets, which means it will be converted to a string using ToString. This means the rectangle’s length will be inserted into the string and displayed on the screen

## Flow of Control with Objects

* Consider what happens when you have multiple objects in the same program, like this:
* class Program  
  {  
   static void Main(string[] args)  
   {  
   Rectangle rect1;  
   rect1 = new Rectangle();  
   rect1.SetLength(12);  
   rect1.SetWidth(3);  
   Rectangle rect2 = new Rectangle();  
   rect2.SetLength(7);  
   rect2.SetWidth(15);  
   }  
  }
  + First, we declare a variable of type Rectangle
  + Then we assign rect1 a value, a new Rectangle object that we instantiate
  + We call the SetLength and SetWidth methods using rect1, and the Rectangle object that rect1 refers to gets its length and width instance variables set to 12 and 3
  + Then we create another Rectangle object and assign it to the variable rect2 . This object has its own copy of the length and width instance variables, not 12 and 3
  + We call the SetLength and SetWidth methods again, using rect2 on the left side of the dot instead of rect1. This means the Rectangle object that rect2 refers to gets its instance variables set to 7 and 15, while the other Rectangle remains unmodified
* The same method code can modify different objects at different times
  + Calling a method transfers control from the current line of code (i.e. in Program.cs) to the method code within the class (Rectangle.cs)
  + The method code is always the same, but the specific object that gets modified can be different each time
  + The variable on the left side of the dot operator determines which object gets modified
  + In rect1.SetLength(12), rect1 is the **calling object**, so SetLength will modify rect1
    - SetLength begins executing with lengthParameter equal to 12
    - The instance variable length in length = lengthParameter refers to rect1’s length
  + In rect2.SetLength(7), rect2 is the calling object, so SetLength will modify rect2
    - SetLength begins executing with lengthParameter equal to 7
    - The instance variable length in length = lengthParameter refers to rect2’s length

#### Accessing object members

* The “dot operator” that we use to call methods is technically the **member access operator**
* A **member** of an object is either a method or an instance variable
* When we write objectName.methodName(), e.g. rect1.SetLength(12), we are using the dot operator to access the “SetLength” member of rect1, which is a method; this means we want to call (execute) the SetLength method of rect1
* We can also use the dot operator to access instance variables, although we usually do not do that because of encapsulation
* If we wrote the Rectangle class like this:
* class Rectangle  
  {  
   public int length;  
   public int width;  
  }
* Then we could write a Main method that uses the dot operator to access the length and width instance variables, like this:
* static void Main(string[] args)  
  {  
   Rectangle rect1 = new Rectangle();  
   rect1.length = 12;  
   rect1.width = 3;  
  }
* But this code violates encapsulation, so we will not do this.

#### Method calls in more detail

* Now that we know about the member access operator, we can explain how method calls work a little better
* When we write rect1.SetLength(12), the SetLength method is executed with rect1 as the calling object – we are accessing the SetLength member of rect1 in particular (even though every Rectangle has the same SetLength method)
* This means that when the code in SetLength uses an instance variable, i.e. length, it will automatically access rect1’s copy of the instance variable
* You can imagine that the SetLength method “changes” to this when you call rect1.SetLength():
* public void SetLength(int lengthParameter)  
  {  
   rect1.length = lengthParameter;  
  }
* Note that we use the “dot” (member access) operator on rect1 to access its length instance variable.
* Similarly, you can imagine that the SetLength method “changes” to this when you call rect2.SetLength():
* public void SetLength(int lengthParameter)  
  {  
   rect2.length = lengthParameter;  
  }
* The calling object is automatically “inserted” before any instance variables in a method
* The keyword this is an explicit reference to “the calling object”
  + Instead of imagining that the calling object’s name is inserted before each instance variable, you could write the SetLength method like this:
  + public void SetLength(int lengthParameter)  
    {  
     this.length = lengthParameter;  
    }
  + This is valid code (unlike our imaginary examples) and will work exactly the same as our previous way of writing SetLength
  + When SetLength is called with rect1.SetLength(12), this becomes equal to rect1, just like lengthParameter becomes equal to 12
  + When SetLength is called with rect2.SetLength(7), this becomes equal to rect2 and lengthParameter becomes equal to 7

#### Methods and instance variables

* Using a variable in an expression means *reading* its value
* A variable only changes when it is on the left side of an assignment statement; this is *writing* to the variable
* A method that uses instance variables in an expression, but does not assign to them, will not modify the object
* For example, consider the ComputeArea method:
* public int ComputeArea()  
  {  
   return length \* width;  
  }
* It reads the current values of length and width to compute their product, but the product is returned to the method’s caller. The instance variables are not changed.
* After executing the following code:
* Rectangle rect1 = new Rectangle();  
  rect1.SetLength(12);  
  rect1.SetWidth(3);  
  int area = rect1.ComputeArea();
* rect1 has a length of 12 and a width of 3. The call to rect1.ComputeArea() computes , and the area variable is assigned this return value, but it does not change rect1.

#### Methods and return values

* Recall the basic structure of a program: receive input, compute something, produce output
* A method has the same structure: it *receives input* from its parameters, *computes* by executing the statements in its body, then *produces output* by returning a value
  + For example, consider this method defined in the Rectangle class:
  + public int LengthProduct(int factor)  
    {  
     return length \* factor;  
    }
  + Its input is the parameter factor, which is an int. In the method body, it computes the product of the rectangle’s length and factor. The method’s output is the resulting product.
* The return statement specifies the output of the method: a variable, expression, etc. that produces some value
* A method call can be used in other code as if it were a value. The “value” of a method call is the method’s return value.
  + In previous examples, we wrote int area = rect1.ComputeArea();, which assigns a variable (area) a value (the return value of ComputeArea())
  + The LengthProduct method can be used like this:
  + Rectangle rect1 = new Rectangle();  
    rect1.SetLength(12);  
    int result = rect1.LengthProduct(2) + 1;
  + When executing the third line of code, the computer first executes the LengthProduct method with argument (input) 2, which computes the product . Then it uses the return value of LengthProduct, which is 24, to evaluate the expression rect1.LengthProduct(2) + 1, producing a result of 25. Finally, it assigns the value 25 to the variable result.
* When writing a method that returns a value, the value in the return statement **must** be the same type as the method’s return type
  + If the value returned by LengthProduct is not an int, we will get a compile error
  + This will not work:
  + public int LengthProduct(double factor)  
    {  
     return length \* factor;  
    }
  + Now that factor has type double, the expression length \* factor will need to implicitly convert length from int to double in order to make the types match. Then the product will also be a double, so the return value does not match the return type (int).
  + We could fix it by either changing the return type of the method to double, or adding a cast to int to the product so that the return value is still an int
* Not all methods return a value, but all methods must have a return type
  + The return type void means “nothing is returned”
  + If your method does not return a value, its return type *must* be void. If the return type is not void, the method *must* return a value.
  + This will cause a compile error because the method has a return type of int but no return statement:
  + public int SetLength(int lengthP)  
    {  
     length = lengthP;  
    }
  + This will cause a compile error because the method has a return type of void, but it attempts to return something anyway:
  + public void GetLength()  
    {  
     return length;  
    }

## Introduction to UML

* UML is a specification language for software
  + UML: Unified Modeling Language
  + Describes design and structure of a program with graphics
  + Does not include “implementation details,” such as code statements
  + Can be used for any programming language, not just C#
  + Used in planning/design phase of software creation, before you start writing code
  + Process: Determine program requirements Make UML diagrams Write code based on UML Test and debug program
* UML Class Diagram elements
* A UML diagram for the ClassName class (text version, image version, svg version)
  + Top box: Class name, centered
  + Middle box: Attributes (i.e. instance variables)
    - On each line, one attribute, with its name and type
    - Syntax: [+/-] [name]: [type]
    - Note this is the opposite order from C# variable declaration: type comes after name
    - Minus sign at beginning of line indicates “private member”
  + Bottom box: Operations (i.e. methods)
    - On each line, one method header, including name, parameters, and return type
    - Syntax: [+/-] [name]([parameter name]: [parameter type]): [return type]
    - Also backwards compared to C# order: parameter types come after parameter names, and return type comes after method name instead of before it
    - Plus sign at beginning of line indicates “public”, which is what we want for methods
* UML Diagram for the Rectangle class
* A UML diagram for the Rectangle class (text version, image version, svg version)
  + Note that when the return type of a method is void, we can omit it in UML
  + In general, attributes will be private (- sign) and methods will be public (+ sign), so you can expect most of your classes to follow this pattern (-s in the upper box, +s in the lower box)
  + Note that there is no code or “implementation” described here: it does not say that ComputeArea will multiply length by width
* Writing code based on a UML diagram
  + Each diagram is one class, everything within the box is between the class’s header and its closing brace
  + For each attribute in the attributes section, write an instance variable of the right name and type
    - See “- width: int”, write private int width;
    - Remember to reverse the order of name and type
  + For each method in the methods section, write a method header with the matching return type, name, and parameters
    - Parameter declarations are like the instance variables: in UML they have a name followed by a type, in C# you write the type name first
  + Now the method bodies need to be filled in - UML just defined the interface, now you need to write the implementation

## Variable Scope

#### Instance and local variables

* Instance variables: Stored (in memory) with the object, shared by all methods of the object. Changes made within a method persist after method finishes executing.
* Local variables: Visible to only one method, not shared. Disappear after method finishes executing. Variables we’ve created before in the Main method (they are local to the Main method!).
* Example: In class Rectangle, we have these two methods:
* public void SwapDimensions()  
  {  
   int temp = length;  
   length = width;  
   width = temp;  
  }  
  public int GetLength()  
  {  
   return length;  
  }
  + temp is a local variable within SwapDimensions, while length and width are instance variables
  + The GetLength method cannot use temp; it is visible only to SwapDimensions
  + When SwapDimensions changes length, that change is persistent – it will still be different when GetLength executes, and the next call to GetLength after SwapDimensions will return the new length
  + When SwapDimensions assigns a value to temp, it only has that value within the current call to SwapDimensions – after SwapDimensions finishes, temp disappears, and the next call to SwapDimensions creates a new temp

#### Definition of scope

* Variables exist only in limited **time** and **space** within the program
* Outside those limits, the variable cannot be accessed – e.g. local variables cannot be accessed outside their method
* Scope of a variable: The region of the program where it is accessible/visible
  + A variable is “in scope” when it is accessible
  + A variable is “out of scope” when it does not exist or cannot be accessed
* Time limits to scope: Scope begins *after* the variable has been declared
  + This is why you cannot use a variable before declaring it
* Space limits to scope: Scope is within the same *code block* where the variable is declared
  + Code blocks are defined by curly braces: everything between matching { and } is in the same code block
  + Instance variables are declared in the class’s code block (they are inside class Rectangle’s body, but not inside anything else), so their scope extends to the entire class
  + Code blocks nest: A method’s code block is inside the class’s code block, so instance variables are also in scope within each method’s code block
  + Local variables are declared inside a method’s code block, so their scope is limited to that single method
* The scope of a parameter (which is a variable) is the method’s code block - it is the same as a local variable for that method
* Scope example:
* public void SwapDimensions()  
  {  
   int temp = length;  
   length = width;  
   width = temp;  
  }  
  public void SetWidth(int widthParam)  
  {  
   int temp = width;  
   width = widthParam;  
  }
  + The two variables named temp have different scopes: One has a scope limited to the SwapDimensions method’s body, while the other has a scope limited to the SetWidth method’s body
  + This is why they can have the same name: variable names must be unique *within the variable’s scope*. You can have two variables with the same name if they are in different scopes.
  + The scope of instance variables length and width is the body of class Rectangle, so they are in scope for both of these methods

#### Variables with overlapping scopes

* This code is legal (compiles) but does not do what you want:
* class Rectangle  
  {  
   private int length;  
   private int width;  
   public void UpdateWidth(int newWidth)  
   {  
   int width = 5;  
   width = newWidth;  
   }  
  }
* The instance variable width and the local variable width have different scopes, so they can have the same name
* But the instance variable’s scope (the class Rectangle) *overlaps* with the local variable’s scope (the method UpdateWidth)
* If two variables have the same name and overlapping scopes, the variable with the *closer* or *smaller* scope **shadows** the variable with the *farther* or *wider* scope: the name will refer *only* to the variable with the smaller scope
* In this case, that means width inside UpdateWidth refers only to the local variable named width, whose scope is smaller because it is limited to the UpdateWidth method. The line width = newWidth actually changes the local variable, not the instance variable named width.
* Since instance variables have a large scope (the whole class), they will always get shadowed by variables declared within methods
* You can prevent shadowing by using the keyword this, like this:
* class Rectangle  
  {  
   private int length;  
   private int width;  
   public void UpdateWidth(int newWidth)  
   {  
   int width = 5;  
   this.width = newWidth;  
   }  
  }
* Since this means “the calling object”, this.width means “access the width member of the calling object.” This can only mean the instance variable width, not the local variable with the same name
* Incidentally, you can also use this to give your parameters the same name as the instance variables they are modifying:
* class Rectangle  
  {  
   private int length;  
   private int width;  
   public void SetWidth(int width)  
   {  
   this.width = width;  
   }  
  }
* Without this, the body of the SetWidth method would be width = width;, which does not do anything (it would assign the parameter width to itself).

## Constants

* Classes can also contain constants
* Syntax: [public/private] const [type] [name] = [value];
* This is a named value that never changes during program execution
* Safe to make it public because it cannot change – no risk of violating encapsulation
* Can only be built-in types (int, double, etc.), not objects
* Can make your program more readable by giving names to “magic numbers” that have some significance
* Convention: constants have names in ALL CAPS
* Example:
* class Calendar  
  {  
   public const int MONTHS = 12;  
   private int currentMonth;  
   //...  
  }
* The value “12” has a special meaning here, i.e. the number of months in a year, so we use a constant to name it.
* Constants are accessed using the name of the class, not the name of an object – they are the same for every object of that class. For example:
* Calendar myCal = new Calendar();  
  decimal yearlyPrice = 2000.0m;  
  decimal monthlyPrice = yearlyPrice / Calendar.MONTHS;

## Reference Types: More Details

* Data types in C# are either value types or reference types
  + This difference was introduced in an earlier lecture (Datatypes and Variables)
  + For a **value type** variable (int, long, float, double, decimal, char, bool) the named memory location stores the exact data value held by the variable
  + For a **reference type** variable, such as string, the named memory location stores a *reference to the value*, not the value itself
  + All objects you create from your own classes, like Rectangle, are reference types
* Object variables are references
  + When you have a variable for a reference type, or “reference variable,” you need to be careful with the assignment operation
  + Consider this code:
  + using System;  
      
    class Program  
    {  
     static void Main(string[] args)  
     {  
     Rectangle rect1 = new Rectangle();  
     rect1.SetLength(8);  
     rect1.SetWidth(10);  
     Rectangle rect2 = rect1;  
     rect2.SetLength(4);  
     Console.WriteLine(  
     $"Rectangle 1: {rect1.GetLength()} "  
     + $"by {rect1.GetWidth()}"  
     );  
     Console.WriteLine(  
     $"Rectangle 2: {rect2.GetLength()} "  
     + $"by {rect2.GetWidth()}"  
     );  
     }  
    }
  + The output is:
  + Rectangle 1: 4 by 10  
    Rectangle 2: 4 by 10
  + The variables rect1 and rect2 actually refer to the same Rectangle object, so rect2.SetLength(4) seems to change the length of “both” rectangles
  + The assignment operator copies the contents of the variable, but a reference variable contains a *reference* to an object – so that’s what gets copied (in Rectangle rect2 = rect1), not the object itself
  + In more detail:
    - Rectangle rect1 = new Rectangle() creates a new Rectangle object somewhere in memory, then creates a reference variable named rect1 somewhere else in memory. The variable named rect1 is initialized with the memory address of the Rectangle object, i.e. a reference to the object
    - rect1.SetLength(8) reads the address of the Rectangle object from the rect1 variable, finds the object in memory, and executes the SetLength method on that object (changing its length to 8)
    - rect1.SetWidth(10) does the same thing, finds the same object, and sets its width to 10
    - Rectangle rect2 = rect1 creates a reference variable named rect2 in memory, but does not create a new Rectangle object. Instead, it initializes rect2 with the same memory address that is stored in rect1, referring to the same Rectangle object
    - rect2.SetLength(4) reads the address of a Rectangle object from the rect2 variable, finds that object in memory, and sets its length to 4 – but this is the exact same Rectangle object that rect1 refers to
* Reference types can also appear in method parameters
  + When you call a method, you provide an argument (a value) for each parameter in the method’s declaration
  + Since the parameter is really a variable, the computer will then assign the argument to the parameter, just like variable assignment
    - For example, when you write rect1.SetLength(8), there is an implicit assignment lengthParameter = 8 that gets executed before executing the body of the SetLength method
  + This means if the parameter is a reference type (like an object), the parameter will get a copy of the reference, not a copy of the object
  + When you use the parameter to modify the object, you will modify the same object that the caller provided as an argument
  + This means objects can change other objects!
  + For example, imagine we added this method to the Rectangle class:
  + public void CopyToOther(Rectangle otherRect)  
    {  
     otherRect.SetLength(length);  
     otherRect.SetWidth(width);  
    }
  + It uses the SetLength and SetWidth methods to modify its parameter, otherRect. Specifically, it sets the parameter’s length and width to its own length and width.
  + The Main method of a program could do something like this:
  + Rectangle rect1 = new Rectangle();  
    Rectangle rect2 = new Rectangle();  
    rect1.SetLength(8);  
    rect1.SetWidth(10);  
    rect1.CopyToOther(rect2);  
    Console.WriteLine($"Rectangle 2: {rect2.GetLength()} "  
     + $"by {rect2.GetWidth()}");
    - First it creates two different Rectangle objects (note the two calls to new), then it sets the length and width of one object, using rect1.SetLength and rect1.SetWidth
    - Then it calls the CopyToOther method with an argument of rect2. This transfers control to the method and (implicitly) makes the assignment otherRect = rect2
    - Since otherRect and rect2 are now reference variables referring to the same object, the calls to otherRect.SetLength and otherRect.SetWidth within the method will modify that object
    - After the call to CopyToOther, the object referred to by rect2 has a length of 8 and a width of 10, even though we never called rect2.SetLength or rect2.SetWidth

# Constructors and Methods

## Default Values and the ClassRoom Class

* In lab, you were asked to execute a program like this:
* using System;  
    
  class Program  
  {  
   static void Main(string[] args)  
   {  
   Rectangle myRect = new Rectangle();  
   Console.WriteLine($"Length is {myRect.GetLength()}");  
   Console.WriteLine($"Width is {myRect.GetWidth()}");  
   }  
  }
* Note that we create a Rectangle object, but do not use the SetLength or SetWidth methods to assign values to its instance variables. It displays the following output:
* Length is 0  
  Width is 0
* This works because the instance variables length and width have a default value of 0, even if you never assign them a value
* Local variables, like the ones we write in the Main method, do *not* have default values. You must assign them a value before using them in an expression.
  + For example, this code will produce a compile error:
  + int myVar1;  
    int myVar2 = myVar1 + 5;
  + You cannot assume myVar1 will be 0; it has no value at all until you use an assignment statement.
* When you create (instantiate) a new object, its instance variables will be assigned specific default values based on their type:

| **Type** | **Default Value** |
| --- | --- |
| Numeric types | 0 |
| string | null |
| objects | null |
| bool | false |
| char | '\0' |

* Remember, null is the value of a reference-type variable that refers to “nothing” - it does not contain the location of any object at all. You cannot do anything with a reference variable containing null.

#### A class we will use for subsequent examples

* ClassRoom: Represents a room in a building on campus
* UML Diagram:
* A UML diagram for the ClassRoom class (text version, image version, svg version)
  + There are two attributes: the name of the building (a string) and the room number (an int)
  + Each attribute will have a “getter” and “setter” method
* Implementation:
* class ClassRoom  
  {  
   private string building;  
   private int number;  
    
   public void SetBuilding(string buildingParam)  
   {  
   building = buildingParam;  
   }  
    
   public string GetBuilding()  
   {  
   return building;  
   }  
    
   public void SetNumber(int numberParam)  
   {  
   number = numberParam;  
   }  
    
   public int GetNumber()  
   {  
   return number;  
   }  
  }
  + Each attribute is implemented by an instance variable with the same name
  + To write the “setter” for the building attribute, we write a method whose return type is void, with a single string-type parameter. Its body assigns the building instance variable to the value in the parameter buildingParam
  + To write the “getter” for the building attribute, we write a method whose return type is string, and whose body returns the instance variable building
* Creating an object and using its default values:
* using System;  
    
  class Program  
  {  
   static void Main(string[] args)  
   {  
   ClassRoom english = new ClassRoom();  
   Console.WriteLine(  
   $"Building is {english.GetBuilding()}"  
   );  
   Console.WriteLine(  
   $"Room number is {english.GetNumber()}"  
   );  
   }  
  }
* This will print the following output:
* Building is  
  Room number is 0
* Remember that the default value of a string variable is null. When you use string interpolation on null, you get an empty string.

## Constructors

* Instantiation syntax requires you to write parentheses after the name of the class, like this:
* ClassRoom english = new ClassRoom();
* Parentheses indicate a method call, like in Console.ReadLine() or english.GetBuilding()
* In fact, the instantiation statement new ClassRoom() does call a method: the **constructor**
* Constructor: A special method used to create an object. It “sets up” a new instance by **initializing its instance variables**.
* If you do not write a constructor in your class, C# will generate a “default” constructor for you – this is what’s getting called when we write new ClassRoom() here
* The default constructor initializes each instance variable to its default value – that’s where default values come from

#### Writing a constructor

* Example for ClassRoom:
* public ClassRoom(string buildingParam, int numberParam)  
  {  
   building = buildingParam;  
   number = numberParam;  
  }
* To write a constructor, write a method whose name is *exactly the same* as the class name
* This method has *no return type*, not even void. It does not have a return statement either
* For ClassRoom, this means the constructor’s header starts with public ClassRoom
  + You can think of this method as “combining” the return type and name. The name of the method is ClassRoom, and its output is of type ClassRoom, since the return value of new ClassRoom() is always a ClassRoom object
  + You do not actually write a return statement, though, because new will always return the new object after calling the constructor
* A custom constructor usually has parameters that correspond to the instance variables: for ClassRoom, it has a string parameter named buildingParam, and an int parameter named numberParam
  + Note that when we write a method with two parameters, we separate the parameters with a comma
* The body of a constructor must assign values to **all** instance variables in the object
* Usually this means assigning each parameter to its corresponding instance variable: initialize the instance variable to equal the parameter
  + Very similar to calling both “setters” at once
* Using a constructor
* An instantiation statement will call a constructor for the class being instantiated
* Arguments in parentheses must match the parameters of the constructor
* Example with the ClassRoom constructor:
* using System;  
    
  class Program  
  {  
   static void Main(string[] args)  
   {  
   ClassRoom csci = new ClassRoom("Allgood East", 356);  
   Console.WriteLine($"Building is {csci.GetBuilding()}");  
   Console.WriteLine($"Room number is {csci.GetNumber()}");  
   }  
  }
* This program will produce this output:
* Building is Allgood East  
  Room number is 356
* The instantiation statement new ClassRoom("Allgood East", 356) first creates a new “empty” object of type ClassRoom, then calls the constructor to initialize it. The first argument, “Allgood East”, becomes the constructor’s first parameter (buildingParam), and the second argument, 356, becomes the constructor’s second parameter (numberParam).
* After executing the instantiation statement, the object referred to by csci has its instance variables set to these values, even though we never called SetBuilding or SetNumber

#### Methods with multiple parameters

* The constructor we wrote is an example of a method with two parameters
* The same syntax can be used for ordinary, non-constructor methods, if we need more than one input value
* For example, we could write this method in the Rectangle class:
* public void MultiplyBoth(int lengthFactor, int widthFactor)  
  {  
   length \*= lengthFactor;  
   width \*= widthFactor;  
  }
* The first parameter has type int and is named lengthFactor. The second parameter has type int and is named widthFactor
* You can call this method by providing two arguments, separated by a comma:
* Rectangle myRect = new Rectangle();  
  myRect.SetLength(5);  
  myRect.SetWidth(10);  
  myRect.MultiplyBoth(3, 5);
* The first argument, 3, will be assigned to the first parameter, lengthFactor. The second argument, 5, will be assigned to the second parameter, widthFactor
* The order of the arguments matters when calling a multi-parameter method. If you write myRect.MultiplyBoth(5, 3), then lengthFactor will be 5 and widthFactor will be 3.
* The type of each argument must match the type of the corresponding parameter. For example, when you call the ClassRoom constructor we just wrote, the first argument must be a string and the second argument must be an int

#### Writing multiple constructors

* Remember that if you do not write a constructor, C# generates a “default” one with no parameters, so you can write new ClassRoom()
* Once you add a constructor to your class, C# will **not** generate a default constructor
  + This means once we write the ClassRoom constructor (as shown earlier), this statement will produce a compile error: ClassRoom english = new ClassRoom();
  + The constructor we wrote has 2 parameters, so now you always need 2 arguments to instantiate a ClassRoom
* If you still want the option to create an object with no arguments (i.e. new ClassRoom()), you must write a constructor with no parameters
* A class can have more than one constructor, so it would look like this:
* class ClassRoom  
  {  
   //...  
   public ClassRoom(string buildingParam, int numberParam)  
   {  
   building = buildingParam;  
   number = numberParam;  
   }  
   public ClassRoom()  
   {  
   building = null;  
   number = 0;  
   }  
   //...  
  }
* The “no-argument” constructor must still initialize all the instance variables, even though it has no parameters
  + You can pick any “default value” you want, or use the same ones that C# would use (0 for numeric variables, null for object variables, etc.)
* When a class has multiple constructors, the instantiation statement must decide which constructor to call
* The instantiation statement will call the constructor whose parameters match the arguments you provide
  + For example, each of these statements will call a different constructor:
  + ClassRoom csci = new ClassRoom("Allgood East", 356);  
    ClassRoom english = new ClassRoom();
  + The first statement calls the two-parameter constructor we wrote, since it has a string argument and an int argument (in that order), and those match the parameters (string buildingParam, int numberParam). The second statement calls the zero-parameter constructor since it has no arguments.
  + If the arguments do not match any constructor, it is still an error:
  + ClassRoom csci = new ClassRoom(356, "Allgood East");
  + This will produce a compile error, because the instantiation statement has two arguments in the order int, string, but the only constructor with two parameters needs the first parameter to be a string.

## Writing ToString Methods

* ToString recap
  + String interpolation automatically calls the ToString method on each variable or value
  + ToString returns a string “equivalent” to the object; for example, if num is an int variable containing 42, num.ToString() returns “42”.
  + C# datatypes already have a ToString method, but you need to write a ToString method for your own classes to use them in string interpolation
* Writing a ToString method
  + To add a ToString method to your class, you must write this header: public override string ToString()
  + The access modifier must be public (so other code, like string interpolation, can call it)
  + The return type must be string (ToString must output a string)
  + It must have no parameters (the string interpolation code will not know what arguments to supply)
  + The keyword override means your class is “overriding,” or providing its own version of, a method that is already defined elsewhere – ToString is defined by the base object type, which is why string interpolation “knows” it can call ToString on any object
    - If you do not use the keyword override, then the pre-existing ToString method (defined by the base object type) will be used instead, which only returns the name of the class
  + The goal of ToString is to return a “string representation” of the object, so the body of the method should use all of the object’s attributes and combine them into a string somehow
  + Example ToString method for ClassRoom:
  + public override string ToString()  
    {  
     return building + " " + number;  
    }
    - There are two instance variables, building and number, and we use both of them
    - A natural way to write the name of a classroom is the building name followed by the room number, like “University Hall 124”, so we concatenate the variables in that order
    - Note that we add a space between the variables
    - Note that building is already a string, but number is an int, so string concatenation will implicitly call number.ToString() – ToString methods can call other ToString methods
    - Another way to write the body would be return $"{building} {number}";
* Using a ToString method
  + Any time an object is used in string interpolation or concatenation, its ToString method will be called
  + You can also call ToString by name using the “dot operator,” like any other method
  + This code will call the ToString method we just wrote for ClassRoom:
  + ClassRoom csci = new ClassRoom("Allgood East", 356);  
    Console.WriteLine(csci);  
    Console.WriteLine($"The classroom is {csci}");  
    Console.WriteLine("The classroom is " + csci.ToString());

## Method Signatures and Overloading

#### Name uniqueness in C

* In general, variables, methods, and classes must have unique names, but there are several exceptions
* **Variables** can have the same name if they are in *different scopes*
  + Two methods can each have a local variable with the same name
  + A local variable (scope limited to the method) can have the same name as an instance variable (scope includes the whole class), but this will result in **shadowing**
* **Classes** can have the same name if they are in *different namespaces*
  + This is one reason C# has namespaces: you can name your classes anything you want. Otherwise, if a library (someone else’s code) used a class name, you would be prevented from using that name
  + For example, imagine you were using a “shapes library” that provided a class named Rectangle, but you also wanted to write your own class named Rectangle
  + The library’s code would use its own namespace, like this:
  + namespace ShapesLibrary  
    {  
     class Rectangle  
     {  
     //instance variables, methods, etc.  
     }  
    }
  + Then your own code could have a Rectangle class in your own namespace:
  + namespace MyProject  
    {  
     class Rectangle  
     {  
     //instance variables, methods, etc.  
     }  
    }
  + You can use both Rectangle classes in the same code, as long as you specify the namespace, like this:
  + MyProject.Rectangle rect1 = new MyProject.Rectangle();  
    ShapesLibrary.Rectangle rect2 = new ShapesLibrary.Rectangle();
* **Methods** can have the same name if they have *different signatures*; this is called **overloading**
  + We’ll explain signatures in more detail in a minute
  + Briefly, methods can have the same name if they have different parameters
  + For example, you can have two methods named Multiply in the Rectangle class, as long as one has one parameter and the other has two parameters:
  + public void Multiply(int factor)  
    {  
     length \*= factor;  
     width \*= factor;  
    }  
    public void Multiply(int lengthFactor, int widthFactor)  
    {  
     length \*= lengthFactor;  
     width \*= widthFactor;  
    }
  + C# understands that these are different methods, even though they have the same name, because their parameters are different. If you write myRect.Multiply(2) it can only mean the first “Multiply” method, not the second one, because there is only one argument.
  + We have used overloading already when we wrote multiple constructors – constructors are methods too. For example, these two constructors have the same name, but different parameters:
  + public ClassRoom(string buildingParam, int numberParam)  
    {  
     building = buildingParam;  
     number = numberParam;  
    }  
    public ClassRoom()  
    {  
     building = null;  
     number = 0;  
    }

#### Method signatures

* A method’s **signature** has 3 components: its **name**, the **type** of each parameter, and the **order** the parameters appear in
* Methods are unique if their *signatures* are unique, which is why they can have the same name
* Signature examples:
  + public void Multiply(int lengthFactor, int widthFactor) – the signature is Multiply(int, int) (name is Multiply, parameters are int and int type)
  + public void Multiply(int factor) – signature is Multiply(int)
  + public void Multiply(double factor) – signature is Multiply(double)
  + These could all be in the same class since they all have different signatures
* Parameter *names* are not part of the signature, just their types
  + Note that the parameter names are omitted when I write down the signature
  + That means these two methods are not unique and could not be in the same class:
  + public void SetWidth(int widthInMeters)  
    {  
     //...  
    }  
    public void SetWidth(int widthInFeet)  
    {  
     //...  
    }
  + Both have the same signature, SetWidth(int), even though the parameters have different names. You might intend the parameters to be different (i.e. represent feet vs. meters), but any int-type parameter is the same to C#
* The method’s return type is not part of the signature
  + So far all the examples have the same return type (void), but changing it would not change the signature
  + The signature of public int Multiply(int factor) is Multiply(int), which is the same as public void Multiply(int factor)
  + The signature “begins” with the name of the method; everything “before” that does not count (i.e. public, int)
* The order of parameters is part of the signature, as long as the types are different
  + Since parameter name is not part of the signature, only the type can determine the order
  + These two methods have different signatures:
  + public int Update(int number, string name)  
    {  
     //...  
    }  
    public int Update(string name, int number)  
    {  
     //..  
    }
  + The signature of the first method is Update(int, string). The signature of the second method is Update(string, int).
  + These two methods have the same signature, and could not be in the same class:
  + public void Multiply(int lengthFactor, int widthFactor)  
    {  
     //...  
    }  
    public void Multiply(int widthFactor, int lengthFactor)  
    {  
     //...  
    }
  + The signature for both methods is Multiply(int, int), even though we switched the order of the parameters – the name does not count, and they are both int type
* Constructors have signatures too
  + The constructor ClassRoom(string buildingParam, int numberParam) has the signature ClassRoom(string, int)
  + The constructor ClassRoom() has the signature ClassRoom()
  + Constructors all have the same name, but they are unique if their signatures (parameters) are different

#### Calling overloaded methods

* Previously, when you used the dot operator and wrote the name of a method, the name was enough to determine which method to execute – myRect.GetLength() would call the GetLength method
* When a method is overloaded, you must use the entire signature to determine which method gets executed
* A method call has a “signature” too: the name of the method, and the type and order of the arguments
* C# will execute the method whose signature matches the signature of the method call
* Example: myRect.Multiply(4); has the signature Multiply(int), so C# will look for a method in the Rectangle class that has the signature Multiply(int). This matches the method public void Multiply(int factor)
* Example: myRect.Multiply(3, 5); has the signature Multiply(int, int), so C# will look for a method with that signature in the Rectangle class. This matches the method public void Multiply(int lengthFactor, int widthFactor)
* The same process happens when you instantiate a class with multiple constructors: C# calls the constructor whose signature matches the signature of the instantiation
* If no method or constructor matches the signature of the method call, you get a compile error. You still cannot write myRect.Multiply(1.5) if there is no method whose signature is Multiply(double).

## Constructors in UML

* Now that we can write constructors, they should be part of the UML diagram of a class
  + No need to include the default constructor, or one you write yourself that takes no arguments
  + Non-default constructors go in the operations section (box 3) of the UML diagram
  + Similar syntax to a method: [+/-] <<constructor>> [name]([parameter name]: [parameter type]) (where <> is sometimes replaced with «constructor»)
  + Note that the name will always match the class name
  + No return type, ever
  + Annotation “<<constructor>>” is nice, but not necessary: if the method name matches the class name, it is a constructor
* Example for ClassRoom:
* A UML diagram for the ClassRoom class (text version, image version, svg version)

# Properties

## Introduction

* Attributes are implemented with a standard “template” of code
* Remember, “attribute” is the abstract concept of some data stored in an object; “instance variable” is the way that data is actually stored
* First, declare an instance variable for the attribute
* Then write a “getter” method for the instance variable
* Then write a “setter” method for the instance variable
* With this combination of instance variable and methods, the object has an attribute that can be read (with the getter) and written (with the setter)
* For example, this code implements a “width” attribute for the class Rectangle:
* class Rectangle  
  {  
   private int width;  
   public void SetWidth(int value)  
   {  
   width = value;  
   }  
   public int GetWidth()  
   {  
   return width;  
   }  
  }
* Note that there is a lot of repetitive or “obvious” code here:
  + The name of the attribute is intended to be “width,” so you must name the instance variable width, and the methods GetWidth and SetWidth, repeating the name three times.
  + The attribute is intended to be type int, so you must ensure that the instance variable, the getter return type, and the setter parameter type are all int. Similarly, this repeats the data type three times.
  + You need to come up with a name for the setter’s parameter, even though it also represents the width (i.e. the new value you want to assign to the width attribute). We usually end up naming it “widthParameter” or “widthParam” or “newWidth” or “newValue.”
* Properties are a “shorthand” way of writing this code: They implement an attribute with less repetition.
* Note that properties are not present in every object-oriented programming language: for example, [Java does not have properties](https://stackoverflow.com/questions/2701077/does-java-have-properties-that-work-the-same-way-properties-work-in-c).

## Writing properties

* Declare an instance variable for the attribute, like before
* A **property declaration** has 3 parts:
  + Header, which gives the property a name and type (very similar to variable declaration)
  + get accessor, which declares the “getter” method for the property
  + set accessor, which declares the “setter” method for the property
* Example code, implementing the “width” attribute for Rectangle (this replaces the code in the previous example):
* class Rectangle  
  {  
   private int width;  
   public int Width  
   {  
   get  
   {  
   return width;  
   }  
   set  
   {  
   width = value;  
   }  
   }  
  }
* Header syntax: [public/private] [type] [name]
* *Convention* (not rule) is to give the property the same name as the instance variable, but capitalized – C# is case sensitive
* get accessor: Starts with the keyword get, then a method body inside a code block (between braces)
  + get is like a method header that always has the same name, and its other features are implied by the property’s header
  + Imagine that it says public int get(): the access modifier (public) and the return type (int) are the same as in the property header
  + Body of get section is exactly the same as body of a “getter”: return the instance variable
* set accessor: Starts with the keyword set, then a method body inside a code block
  + Also a method header with a fixed name, access modifier, return type, and parameter
  + Imagine that it says public void set (int value): the access modifier (public), the return type (void), and the parameter (int value) are the same as in the property header
  + The return type is always void (like a setter)
  + The parameter name is always “value”. In this case, that means the parameter is int value
  + Body of set section looks just like the body of a setter: Assign the parameter to the instance variable (and the parameter is always named “value”). In this case, that means width = value

## Using properties

* Properties are members of an object, just like instance variables and methods
* Access them with the “member access” operator, aka the dot operator
  + For example, myRect.Width will access the property we wrote, assuming myRect is a Rectangle
* A complete example (available [as a complete solution](https:/princomp.github.io/code/projects/Properties_Example.zip)), where the “length” and “width” attributes are implemented with properties:
* ﻿class Rectangle  
  {  
   private int width;  
   public int Width  
   {  
   get { return width; }  
   set { width = value; }  
   }  
   private int length;  
   public int Length  
   {  
   get { return length; }  
   set { length = value; }  
   }  
  }
* Properties “act like” variables: you can assign to them and read from them
* Reading from a property will *automatically* call the get accessor for that property
  + For example,
* Console.WriteLine(  
   $"The width is {myRectangle.Width}");
* will call the get accessor inside the Width property, which in turn executes return width and returns the current value of the instance variable
  + This is equivalent to
* Console.WriteLine(  
   $"The width is {myRectangle.GetWidth()}");
* using the “old” Rectangle code
* Assigning to (writing) a property will *automatically* call the set accessor for that property, with an argument equal to the right side of the = operator
  + For example, myRectangle.Width = 15; will call the set accessor inside the Width property, with value equal to 15
  + This is equivalent to myRectangle.SetWidth(15); using the “old” Rectangle code

## In More Details

* Note that in a property, value is what is called a [*contextual keyword*](https://learn.microsoft.com/en-us/dotnet/csharp/language-reference/language-specification/lexical-structure#644-keywords): it is not a reserved word in C# (it could be used as an identifier), but *inside a property* it refers to something special, the name of the set method parameter.
* In the following code:
* private int width;  
  public int Width  
  {  
   get  
   {  
   return width;  
   }  
   set  
   {  
   width = value;  
   }  
  }
* The attribute width is called the Width property’s *backing field*: it holds the data assigned to the property.
* When the property’s get *and* set accessors are trivial (like the ones above), we can simply omit their bodies completely. That is, the previous Width property could be implemented using
* public int Width { get; set; }
* This is called *automatic properties* (or *auto-properties*). Note that in this case, we do not need to declare the property’s backing field (that is, no need to have private int width;), but cannot refer to it!
* Conversely, the get and set accessors can contain arbitrarily convoluted code:
* public int Length  
  {  
   get { return length; }  
   set {  
   if (value < 0) {  
   length = -value;  
   }  
   else if (value == 0) {  
   length = 1;  
   }  
   else {   
   length = value;  
   }  
   }  
  }
* Note however that if either the set or get accessor is not the “trivial” one, then automatic properties cannot be used and the other accessor must be specified.
  + For example, in the above code, simply writing get; instead of get { return length; } would give a compilation error.
* Note that properties can exist without backing field, and they can be *read-only* (that is, without a set accessor) or *write-only* (that is, without a get accessor, but this is rarer).
  + An example of read-only property is as follows:
  + class Circle  
    {  
     public decimal Diameter { get; set; }  
     // The constructor below sets the value  
     // of the property's backing field through  
     // the property's set accessor.  
     public Circle(decimal dP)  
     {  
     Diameter = dP;  
     }  
     // The Radius property below is  
     // 1. read-only (no set accessor),  
     // 2. without a backing field.  
     public decimal Radius {  
     get { return Diameter / 2; }  
     }  
    }
* It is possible to set a “custom default value” for properties using a *property initializer*, as follows:
* public double Diameter { get; set; } = -1;
* In this case, the property’s backing field value will be -1 by default. Properties with an initializer can be read-only:
* public int MaximumValue { get; } = 999;
* Finally, properties can be static as well:
* public static string Explanation { get; set; } = "A Circle has for radius its diameter divided by 2.";
* This means that the property is shared among all instances of the class. It also means that the property can be accessed without creating an object (instantiating the class) first. For example, you might access the above property this way:
* Console.WriteLine(Circle.Explanation);
* and its value can be changed, for instance by appending a string to it:
* Circle.Explanation += "\nIts circumference is π multiplied by its diameter.";

Putting together some of the elements discussed above, we can get for example the following:

class Circle  
{  
 public decimal Diameter { get; set; }  
  
 // The constructor below sets the value  
 // of the property's backing field through  
 // the property's set accessor.  
 public Circle(decimal dP)  
 {  
 Diameter = dP;  
 }  
  
 // The Radius property below is  
 // 1. read-only (no set accessor),  
 // 2. without a backing field.  
 public decimal Radius  
 {  
 get { return Diameter / 2; }  
 }  
  
 // The Circumference property below  
 // is also read-only, and without  
 // a backing field.  
 public decimal Circumference  
 {  
 get { return Diameter \* PI; }  
 }  
  
 // Using properties with a \*static\* attribute:  
 private static string explanation =  
 "The diameter is the radius times 2, the circumference is the diameter times pi.";  
 public static string Explanation  
 {  
 get { return explanation; }  
 set { explanation = value; }  
 }  
  
 // Using static, read-only property:  
 public static decimal PI { get; } = 3.1415926535897931M;  
  
 // Pretty much the same as  
 // public const decimal PI = 3.1415926535897931M;  
  
 public override string ToString()  
 {  
 return "Your circle has a diameter of "  
 + Diameter  
 + "\nA radius of "  
 + Radius  
 + "\nCircumference of "  
 + Circumference;  
 }  
}

[*(Download this code)*](https:/princomp.github.io/code/projects/Circle_with_properties.zip)

## Properties in UML Class Diagrams

### Simple Notation

* Since properties represent (or, rather, allow to access) attributes, they go in the “attributes” box (the second box)
* If a property will simply “get” and “set” an instance variable of the same name, you do *not* need to write the instance variable in the box
  + No need to write both the property Width and the instance variable width
* Syntax: [+/-] «property» [name]: [type] (where “«property»” is sometimes used in place of «property»).
* Note that the access modifier (+ or -) is for the property, not the instance variable, so it is + if the property is public (which it usually is)
* Example for Rectangle, assuming we converted both attributes to use properties instead of getters and setters:
* A UML diagram for the Rectangle class (text version, image version, svg version)
* We no longer need to write all those setter and getter methods, since they are “built in” to the properties

#### More Accurate Notation

In general, instead of writing for example

+ «properties» Explanation: string

one can write

+ «get, set» Explanation: string

or even

+ «set» Explanation: string  
+ «get» Explanation: string

The benefit of this notation is that read-only properties can easily be integrated in the UML class diagram, by simply omitting the «set» line:

+ «get» Radius : decimal

## Properties and Security

*The following discussion is related to the general topic of* [try-catch-finally *scope*](file:///C:\Users\NAFAHA\Downloads\misc\exceptions#scoping-in-try-catch-finally-statements) *but can be read independently.*

Properties are extremely useful to insure that an attribute will never receive a “forbidden” value (for example, outside a range). Since every access to the attribute is “safeguarded” by the property, it can provide some security *only if used correctly*.

For example, consider the following code:

!include code/projects/PropertySafety/PropertySafety/PropertySafety.cs

[*(Download this code)*](https:/princomp.github.io/code/projects/PropertySafety.zip)

It may be easy to consider that sensibleData will *never* receive the value "Forbidden word" if every access to sensibleData is made through the property SensibleData. However, **this is plain wrong**! Indeed, consider the following (where you may replace the exception bit with return; if you are not familiar with this concept yet).

!include code/projects/PropertySafety/PropertySafety/Program.cs

[*(Download this code)*](https:/princomp.github.io/code/projects/PropertySafety.zip)

It will display

Intrusion detected, aborting!  
Attempted to read or write protected memory. This is often an indication that other memory is corrupt.  
Forbidden word

Where the last line indicate that the attribute *was set to* "Forbidden word"*!*

The correct fix is to **first test, then set**, so that an incorrect value would **never be assigned**. In the previous example, simply moving sensibleData = value; to the end of the set would fix this issue.

# The static Keyword

## Static Methods

### Different ways of calling methods

* Usually you call a method by using the “dot operator” (member access operator) on an object, like this:
* Rectangle rect = new Rectangle();  
  rect.SetLength(12);
* The SetLength method is defined in the Rectangle class. In order to call it, we need an *instance* of that class, which in this case is the object rect.
* However, sometimes we have written code where we call a method using the dot operator on the name of a class, not an object. For example, the familiar WriteLine method:
* Console.WriteLine("Hello!");
* Notice that we have never needed to write new Console() to instantiate a Console object before calling this method.
* More recently, we learned about the Array.Resize method, which can be used to resize an array. Even though arrays are objects, we call the Resize method on the Array class, not the particular array object we want to resize:
* int[] myArray = {10, 20, 30};  
  Array.Resize(ref myArray, 6);
* Methods that are called using the name of the class rather than an instance of that class are **static methods**

### Declaring static methods

* Static methods are declared by adding the static keyword to the header, like this:
* class Console  
  {  
   public static void WriteLine(string value)  
   {  
   ...  
   }  
  }
* The static keyword means that this method belongs to the class “in general,” rather than an instance of the class
* Thus, you do not need an object (instance of the class) to call a static method; you only need the name of the class

### static methods and instances

* Normal, non-static methods are always associated with a particular instance (object)
* When a normal method modifies an instance variable, it always “knows” which object to modify, because you need to specify the object when calling it
  + For example, the SetLength method is defined like this:
  + class Rectangle  
    {  
     private int length;  
     private int width;  
     public void SetLength(int lengthParameter)  
     {  
     length = lengthParameter;  
     }  
    }
  + When you call the method with rect.SetLength(12), the length variable automatically refers to the length instance variable stored in rect.
* Static methods are not associated with any instance, and thus **cannot use instance variables**
* For example, we could attempt to declare the ComputeArea method of Rectangle as a static method, but this would not compile:
* class Rectangle  
  {  
   private int length;  
   private int width;  
   public void SetLength(int lengthParameter)  
   {  
   length = lengthParameter;  
   }  
   public static int ComputeArea()  
   {  
   return length \* width;  
   }  
  }
  + To call this static method, you would write Rectangle.ComputeArea();
  + Since no Rectangle object is specified, which object’s length and width should be used in the computation?

### Uses for static methods

* Since static methods cannot access instance variables, they do not seem very useful
* One reason to use them: when writing a function that does not need to “save” any state, and just computes an output (its return value) based on some input (its parameters)
* Math-related functions are usually written as static methods. The .NET library comes with a class named Math that defines several static methods, like these:
* public static double Pow(double x, double y)  
  {  
   //Computes and returns x^y  
  }  
  public static double Sqrt(double x)  
  {  
   //Computes and returns the square root of x  
  }  
  public static int Max(int x, int y)  
  {  
   //Returns the larger of the two numbers x and y  
  }  
  public static int Min(int x, int y)  
  {  
   //Returns the smaller of the two numbers x and y  
  }
* Note that none of them need to use any instance variables.
* Defining several static methods in the same class (like in class Math) helps to group together similar or related functions, even if you never create an object of that class
* Static methods are also useful for providing the program’s “entry point.” Remember that your program must always have a Main method declared like this:
* class Program  
  {  
   static void Main(string[] args)  
   {  
   ...  
   }  
  }
  + When your program first starts, no objects exist yet, which means no “normal” methods can be called
  + The .NET run-time (the interpreter that runs a C# program) must decide what code to execute to make your program start running
  + It can call Program.Main() without creating an object, or knowing anything else about your program, because Main is a static method
* Static methods can be used to “help” other methods, both static and non-static
  + It’s easy to call a static method from within the same class: You can just write the name of the method, without the class name, i.e. MethodName(args) instead of ClassName.MethodName(args)
  + For example, the Array class has a static method named Copy that copies the contents of one array into another array. This makes it very easy to write the Resize method:
  + class Array  
    {  
     public static void Copy(Array source, Array dest, int length)  
     {  
     //Copy [length] elements from source to dest, in the same order  
     }  
     public static void Resize<T>(ref T[] array, int newSize)  
     {  
     T[] newArray = new T[newSize]  
     Copy(array, newArray, Math.Min(array.Length, newSize));  
     array = newArray;  
     }  
    }
  + Since arrays are fixed-size, the only way to resize an array is to create a new array of the new size and copy the data from the old array into the new array. This Resize method is easy to read because the act of copying the data (which would involve a for loop) is written separately, in the Copy method, and Resize just needs to call Copy.
  + Similarly, you can add additional static methods to the class that contains Main, and call them from within Main. This can help you separate a long program into smaller, easier-to-read chunks. It also allows you to re-use the same code multiple times without copying and pasting it.
  + class Program  
    {  
     static void Main(string[] args)  
     {  
     int userNum1 = InputPositiveNumber();  
     int userNum2 = InputPositiveNumber();  
     int part1Result = DoPart1(userNum1, userNum2);  
     DoPart2("Bananas", part1Result);  
     }  
     static int InputPositiveNumber()  
     {  
     int number;  
     bool success;  
     do  
     {  
     Console.WriteLine("Please enter a positive number");  
     success = int.TryParse(Console.ReadLine(), out number);  
     } while(!success || number < 0);  
     return number;  
     }  
     static int DoPart1(int a, int b)  
     {  
     ...  
     }  
     static void DoPart2(string x, int y)  
     {  
     ...  
     }  
    }
  + In this example, our program needs to read two different numbers from the user, so we put the input-validation loop into the InputPositiveNumber method instead of writing it twice in the Main method. It then has two separate “parts” (computing some result with the two user-input numbers, and combining that computed number with a string to display some output), which we write in the two methods DoPart1 and DoPart2. This makes our actual Main method only 4 lines long.

## Static Variables

### Defining static variables

* The static keyword can be used in something that looks like an instance variable declaration:
* class Rectangle  
  {  
   private static int NumRectangles = 0;  
   ...  
  }
* This declares a variable that is stored with the class definition, not inside an object (it is *not* an instance variable)
* Unlike an instance variable, there is only one copy in the entire program, and any method that refers to NumRectangles will access the *same* variable, no matter which object the method is called on
* Since it is not an instance variable, it does not get initialized in the constructor. Instead, you must initialize it with a value when you declare it, more like a local variable (in this case, NumRectangles is initialized to 0).
* It’s OK to declare a static variable with the public access modifier, because it is not part of any object’s state. Thus, accessing the variable from outside the class will not violate encapsulation, the principle that an object’s state should only be modified by that object.
  + For example, we could use the NumRectangles variable to count the number of rectangles in a program by making it public. We could define it like this:
  + class Rectangle  
    {  
     public static int NumRectangles = 0;  
     ...  
    }
  + and use it like this, in a Main method:
  + Rectangle myRect = new Rectangle();  
    Rectangle.NumRectangles++;  
    Rectangle myOtherRect = new Rectangle();  
    Rectangle.NumRectangles++;

### Using static variables

* Since all instances of a class share the same static variables, you can use them to keep track of information about “the class as a whole” or “all the objects of this type”
* A common use for static variables is to count the number of instances of an object that have been created so far in the program
  + Instead of “manually” incrementing this counter, like in our previous example, we can increment it inside the constructor:
  + class Rectangle  
    {  
     public static int NumRectangles = 0;  
     private int length;  
     private int width;  
     public Rectangle(int lengthP, int widthP)  
     {  
     length = lengthP;  
     width = widthP;  
     NumRectangles++;  
     }  
    }
  + Each time this constructor is called, it initializes a new Rectangle object with its own copy of the length and width variables. It also increments the single copy of the NumRectangles variable that is shared by all Rectangle objects.
  + The variable can still be accessed from the Main method (because it is public), where it could be used like this:
  + Rectangle rect1 = new Rectangle(2, 4);  
    Rectangle rect2 = new Rectangle(7, 5);  
    Console.WriteLine(Rectangle.NumRectangles  
     + " rectangle objects have been created");
  + When rect1 is instantiated, its copy of length is set to 2 and its copy of width is set to 4, then the single NumRectangles variable is incremented to 1. Then, when rect2 is instantiated, its copy of length is set to 7 and its copy of width is set to 5, and the NumRectangles variable is incremented to 2.
* Static variables are also useful for **constants**
  + The const keyword, which we learned about earlier, is actually very similar to static
  + A const variable is just a static variable that cannot be modified
  + Like a static variable, it can be accessed using the name of the class where it is defined (e.g. Math.PI), and there is only one copy for the entire program

### Static methods and variables

* Static methods cannot access instance variables, but they *can* access static variables
* There is no ambiguity when accessing a static variable: you do not need to know which object’s variable to access, because there is only one copy of the static variable shared by all objects
* This means you can write a “getter” or “setter” for a static variable, as long as it is a static method. For example, we could improve our NumRectangles counter by ensuring that the Main method can only read it through a getter method, like this:
* class Rectangle  
  {  
   private static int NumRectangles = 0;  
   private int length;  
   private int width;  
   public Rectangle(int lengthP, int widthP)  
   {  
   length = lengthP;  
   width = widthP;  
   NumRectangles++;  
   }  
   public static int GetNumRectangles()  
   {  
   return NumRectangles;  
   }  
  }
  + The NumRectangles variable is now declared private, which means only the Rectangle constructor will be able to increment it. Before, it would have been possible for the Main method to execute something liek Rectangle.NumRectangles = 1; and throw off the count.
  + The GetNumRectangles method cannot access length or width because they are instance variables, but it can access NumRectangles
  + The static method would be called from the Main method like this:
  + Rectangle rect1 = new Rectangle(2, 4);  
    Rectangle rect2 = new Rectangle(7, 5);  
    Console.WriteLine(Rectangle.GetNumRectangles()  
     + " rectangle objects have been created");

### Summary of static access rules

* Static variables and instance variables are both **fields** of a class; they can also be called “static fields” and “non-static fields”
* This table summarizes how methods are allowed to access them:

|  | Static Field | Non-static Field |
| --- | --- | --- |
| Static method | Yes | No |
| Non-static method | Yes | Yes |

## Static Classes

* The static keyword can also be used in a class declaration
* If a class is declared static, all of its members (fields and methods) must be static
* This is useful for classes that serve as “utility libraries” containing a collection of functions, and are not supposed to be instantiated and used as objects
* For example, the Math class is declared like this:
* static class Math  
  {  
   public static double Sqrt(double x)  
   {  
   ...  
   }  
   public static double Pow(double x, double y)  
   {  
   ...  
   }  
  }
* There is no need to ever create a Math object, but all of these methods belong together (within the same class) because they all implement standard mathematical functions.

# Generic Type Parameter

## Introduction

Imagine that you want to write a method that takes as an argument an array and returns an array of the same type, but with the values reversed. You may write the following code:

public class Helper{  
 public static int[] Reverse(int[] arrayP)  
 {  
 int[] result = new int[arrayP.Length];  
 int j = 0;  
 for (int i = arrayP.Length - 1; i >= 0; i--)  
 {  
 result[j] = arrayP[i];  
 j++;  
 }  
 return result;  
 }  
}

Then, this method could be used as follows:

int[] array1 = {0, 2, 3, 6};  
int[] array1reversed = Helper.Reverse(array1);

And then array1reversed would contain 6, 3, 2, 0.

This method works as intended, but you can use it only with arrays of *integers*. If you want to use a similar method with arrays of, say, char, then you need to copy-and-paste the code above and to replace every occurrence of int by char. This is not very efficient, and it is error-prone.

## Generic Types

There is a tool in C# to avoid having to be *too* specific, and to be able to tell the compiler that the method will work “with some type”, called [generic type parameter](https://learn.microsoft.com/en-us/dotnet/csharp/programming-guide/generics/generic-type-parameters), using the keyword T. In essence, <T> is affixed after the name of the method to signal that the method will additionally require to instantiate T with a particular type.

The previous method would become:

public class Helper{  
 public static T[] Reverse<T>(T[] arrayP)  
 {  
 T[] result = new T[arrayP.Length];  
 int j = 0;  
 for (int i = arrayP.Length - 1; i >= 0; i--)  
 {  
 result[j] = arrayP[i];  
 j++;  
 }  
 return result;  
 }  
}

where three occurrences of int[] were replaced by T[], and <T> was additionally added between the name of the method and its parameters. This method is used as follows:

int[] array1 = {0, 2, 3, 6};  
int[] array1reversed = Helper.Reverse<int>(array1);  
  
char[] array2 = {'a', 'b', 'c'};  
char[] array2reversed = Helper.Reverse<char>(array2);

In essence, Reverse<int> tells C# that Reverse will be used with T being int (not int[], as the method uses T[] for its argument and return type). Note that to use *the same method* with char, we simply use Reverse<char>, and then we provide an array of char as parameters, and obtain an array of char in return.

## Implicitly Typed Local Variables

Sometimes, the body of the method needs to declare variable with the same type as T. Indeed, imagine, for example, that we want to add to our Helper class a method that returns a string description of an array. We can write the following:

public static string Description(int[] arrayP)  
{  
 string returned = "";  
 foreach (int element in arrayP)  
 {  
 returned += element + " ";  
 }  
 return returned;  
}

but this method is specific to arrays of int, and we would have to write another one for char, for example. Making the header generic is “easy”, as we can use, as before:

public static string Description<T>(T[] arrayP)

but the body is problematic: what should be the type of the element variable in the header of the foreach? We cannot simply use T, but we can use *implicitly typed variable*. This technique, that uses the keyword var essentially tells C# to … figure out the type of the variable. In that case, since C# knows the type of the array you are passing, it can easily infer the type of its elements.

We can then rewrite the previous method as follows:

public static string Description<T>(T[] arrayP)  
{  
 string returned = "";  
 foreach (var element in arrayP)  
 {  
 returned += element + " ";  
 }  
 return returned;  
}

and use it with

Console.WriteLine(Helper.Display<char>(array2);

for example.

# Inheritance

## Motivation

* One of the benefit of Object-Oriented Programming is to re-use the same class to handle multiple instantiations. This saves the programmer having to repeat or copy the same code again and again.
* But classes can *themselves* re-use code from other classes: this similarly saves the programmer from having to copy the same code again and again.
* Consider for example that a programmer has to write a class for cars, a class for bikes, and a class for planes.
  + All classes will share some attributes: they will all need, for example, an attribute for their number of wheels, one for their passenger capacity, one for their average speed, one for their average price per mile, and so on.
  + All classes may also share some method: typically, how the number of wheels can be accessed, or how to convert their price per mile to a price per kilometer.
  + However, some attributes will be proper to some classes: fork length makes sense only for bikes[[8]](#footnote-8), maximum altitude only makes sense for planes, trunk size only make sense for cars, etc.
  + This is an example of *inheritance*: the programmer will implement one class for vehicle containing all the shared attributes and methods, and will have the class for e.g., bikes, *inherits* from the vehicle class.
* The most general class is called *the base class* (or superclass). The most particular class is called *the derived class* (or subclass).

## Vehicle Example

Consider the following class:

A UML diagram for the Vehicle class (text version, image version, svg version)

with the following implementation:

public class Vehicle  
{  
 public string Color { get; set; }  
 private int numberOfWheels;  
  
 public void SetNOW(int nowP)  
 {  
 if (nowP > 0)  
 numberOfWheels = nowP;  
 else  
 numberOfWheels = -1;  
 // We could also decide to throw an exception here.  
 }  
  
 public Vehicle()  
 {  
 Color = "undefined";  
 numberOfWheels = -1;  
 }  
  
 public Vehicle(string cP, int nowP)  
 {  
 Color = cP;  
 numberOfWheels = nowP;  
 }  
  
 public override string ToString()  
 {  
 return $"Number of wheels: {numberOfWheels}"  
 + $"\nColor: {Color}";  
 }  
}

and say that we want to extend it to accommodate bikes. Bikes have, in addition to a color and a number of wheels, a fork length. Note that no other vehicle have a fork length, so it does not make sense to add this attribute to the Vehicle class.

A possible implementation is as follows:

public class Bike : Vehicle  
{  
 public double ForkLength { get; set; }  
  
 public Bike()  
 {  
 ForkLength = -1;  
 SetNOW(2); // or base.setNOW(2);  
 }  
  
 public Bike(string cP, double flP)  
 : base(cP, 2)  
 {  
 ForkLength = flP;  
 }  
  
 public override string ToString()  
 {  
 return base.ToString() + $"\nFork Length: {ForkLength}";  
 }  
}

Note:

* The : Vehicle on the first line, that make Bike a *derived class* from Vehicle. Any Bike object will have all the attributes and properties of the Vehicle class, in addition to its methods. For example, we can have:
* Bike test2 = new Bike();  
  test2.Color = "Green";
* and the Vehicle Color accessor will be used, since Bike does not have an accessor for Color.
* Implicitly, the Bike() constructor starts by calling the Vehicle() constructor, so that Color and numberOfWheels are actually set to "undefined" and -1, respectively.
* That SetNOW into the Bike() constructor actually refers to the SetNOW method in the Vehicle class. A way of being more explicit would have been to write base.SetNOW instead of SetNOW. In either case, the value -1M is overriden by 2 (since every bike has 2 wheels).
* The : base(cP, 2) instructs to call the
* Vehicle(string cP, int nowP)
* constructor, passing it the values cP and 2 (once again since every bike has 2 wheels).
* The override keyword “discards” the Vehicle ToString method to replace it with a custom ToString method for the Bike class. Note that we can still access what the Vehicle method returns using base.ToString(). Note that, in this particular, we have no choice but to call this base ToString method, since we have no way of accessing numberOfWheels from the Bike class: this attribute is private to the Vehicle class, and has no getter.

The inheritance is represent in UML as follows:

A UML diagram for the Vehicle ⇽ Bike class (text version, image version, svg version)

Observe that the ToString is indicated in the Bike class: this is an indication that the Vehicle’s ToString method is actually overriden in the Bike derived class.

Note that inheritance can be “chained”, as Bike could itself be the base class for a Bicycle class that could have e.g. a saddleType attribute (noting that a motorbike does not have a saddle, but a seat). We could then obtain a code as follows:

﻿public class Bicycle : Bike  
{  
 private string saddleType;  
  
 public Bicycle()  
 {  
 saddleType = "undefined";  
 }  
  
 public Bicycle(string cP, double flP, string sdtP)  
 : base(cP, flP)  
 {  
 saddleType = sdtP;  
 }  
  
 public override string ToString()  
 {  
 return base.ToString() + $"\nSaddle Type: {saddleType}";  
 }  
}

# Polymorphism

## Motivation

[Inheritance](https:/princomp.github.io/lectures/oop/inheritance) provides another very useful mechanism: [(subtype) *polymorphism*](https://en.wikipedia.org/wiki/Polymorphism_(computer_science)#Subtyping). In a nutshell, the idea is that if a Pyramid[[9]](#footnote-9) class extends the Rectangle class, then a Pyramid object can *still access all the* Rectangle*’s public methods, properties and attributes*. Indeed, a Pyramid *is a* Rectangle: this is precisely what polymorphism means.

While the example below is abstract, it can be easily instantiated to e.g., a Cat class inheriting from a Pet class or a Pyramid class inheriting from a Rectangle class.

## Inheriting Attributes, Properties and Methods

Consider the following two classes:

class Class1  
{  
 private string attribute1;  
  
 public void SetAttribute1(string aP)  
 {  
 attribute1 = aP;  
 }  
  
 public string Property1 { get; set; }  
}

class Class1  
{  
 private string attribute1;  
  
 public void SetAttribute1(string aP)  
 {  
 attribute1 = aP;  
 }  
  
 public string Property1 { get; set; }  
}

Then,

* Any Class1 object has an attribute attribute1, a property Property1 and a method SetAttribute1.
* Any Class2 object has the attribute, property and method of a Class1 object, and *in addition*, it has a Property2 property.
* Actually, any object from Class2 *is* an object of Class1 and can be treated as such.

This means that the following code is valid:

class Program  
{  
 static void Main()  
 {  
 Class1 object1 = new Class1();  
 object1.SetAttribute1("Test");  
 object1.Property1 = "Test";  
  
 Class2 object2 = new Class2();  
 object2.SetAttribute1("Test");  
 object2.Property1 = "Test";  
 object2.Property2 = "Test";  
  
 ClassHelper.Method1(object1);  
 ClassHelper.Method1(object2);  
 ClassHelper.Method2(object2);  
 }  
}

[*(Download this code)*](https:/princomp.github.io/code/projects/Polymorphism1.zip)

Note, however, that

* object1.Property2 = "Test"; would not compile, since an object from Class1 cannot access the attributes, properties and methods of Class2.
* ClassHelper.Method2(object1); would also not compile, since an object from Class1 cannot “become” an object of Class2.

Stated differently, an object in Class2 *is a(n object in)* Class1, but the converse is not true: an object in Class1 *is not* an object in Class2.

## Polymorphism and References

Note that a Class1 object can be created using a Class2 constructor, since an object in Class2 *is a(n object in)* Class1. Formally, we can write:

Class1 object3 = new Class2();

and then manipulate object3 like any other \*object from Class1 (it is, in a way, “truncated”). In particular, we can use

object3.Property1 = "Test";

but object3.Property2 = "Test"; would not compile *since we would be trying to access a property of* Class2 *with a* Class1 *object.* Remember that an object in Class1 *is not* an object in Class2, and that the way we declared it, object3 *is* a Class1 object.

## Solving Ambiguity by Overriding

### For Methods

Now, consider the following class implementation and usage:

class Class1  
{  
 public string Test()  
 {  
 return "Class1";  
 }  
}  
  
class Class2 : Class1  
{  
 public string Test()  
 {  
 return "Class2";  
 }  
}

using System;  
  
class Program  
{  
 static void Main()  
 {  
 Class1 object1 = new Class1();  
 Console.WriteLine(object1.Test());  
  
 Class2 object2 = new Class2();  
 Console.WriteLine(object2.Test());  
 }  
}

[*(Download this code)*](https:/princomp.github.io/code/projects/Polymorphism2.zip)

Console.WriteLine(object1.Test()); will display “Class1”: there is no ambiguity, since object1 is a Class1 object, it can access only the methods in its class.

However, the situation is less clear for Console.WriteLine(object2.Test());: since object2 is “at the same time” a Class1 and a Class2 object, which method will be called? In this case, “Class2” will be displayed since C# prefers the “closest” method available (that is, the one in the same class as the calling object). However, a warning will be issued by the compiler because the Test method in Class2 “hides” the inherited method Test from Class1.

A much better code explicitly instructs C# to *override* Class1’s Test method with Class2’s Test method. However, this further requires Class1’s Test method to explicitly give permission to be overriden, using the virtual keyword:

class Class1  
{  
 public virtual string Test()  
 {  
 return "Class1";  
 }  
}  
  
class Class2 : Class1  
{  
 public override string Test()  
 {  
 return "Class2";  
 }  
}

[*(Download this code)*](https:/princomp.github.io/code/projects/Polymorphism3.zip)

This program will also display, as expected,

Class1  
Class2

but this time the compiler will not complain: there is no ambiguity, as Class2’s Test method must explicitly take precedence when an object in Class2 is calling a Test method.

Note that by default, methods are non-virtual, and non-virtual method cannot be overridden. However, overriding methods are treated as virtual and can be overridden themselves, unless they use the sealed keyword, as follows:

public override sealed string Test(){…}

Such a method **cannot** be overridden by classes inheriting from the class to which they belong[[10]](#footnote-10).

Last but not least, note that an override method **must** have the same signature as the overridden method.

### For Attributes and Properties

Virtual attributes and properties can similarly be overridden, provided of course the overriding property or attribute has the same datatype and name as the virtual method or property. Consider for instance an int Property in a Class1 class with no requirement that is inherited by a Class2 that wish to forbid negative values. One could do the following:

class Class1  
{  
 public virtual int Property { get; set; }  
}

using System;  
  
class Class2 : Class1  
{  
 private int attribute;  
 public override int Property  
 {  
 set  
 {  
 if (value < 0)  
 throw new ArgumentOutOfRangeException();  
 else  
 attribute = value;  
 }  
 get { return attribute; }  
 }  
}

Note that the property in Class2 has a backing field while there is no need for it in Class1.

The following would then throw an exception when the object2.Property = -12; statement would be executed:

using System;  
  
class Program  
{  
 static void Main()  
 {  
 Class1 object1 = new Class1();  
 object1.Property = -12;  
  
 Class2 object2 = new Class2();  
 try  
 {  
 object2.Property = -12;  
 }  
 catch  
 {  
 Console.WriteLine(  
 "In Class2, Property cannot be set to a negative value."  
 );  
 }  
 }  
}

[*(Download this code)*](https:/princomp.github.io/code/projects/Polymorphism4.zip)

Note that, as for methods, overriding properties are by default virtual and can be overridden, for example as follows:

class Class3 : Class2  
{  
 public override int Property { set; get; }  
}

making Class3 “restore” the behavior of Class1’s Proporty using automatic properties.

# Abstract Classes

## Motivation

Consider the following situation:

* We want to implement a class for students, and one for employees.
* We realize that those class overlap heavily: they both need properties for an id, a name, an emergency phone number, an address, etc., identical methods to e.g., implement an automated alert system, etc.
* However, they do not overlap perfectly: for example, students will have a major but employees won’t, and employee will have an hourly wage but students won’t. Also, some checks will be different: while both students and employees will have an id, the former will always have to start with the letter ‘S’, but the latter won’t have any requirement.
* So we really do need two different classes, but would like for them both to inherit a “Person” class that implements all the overlapping properties, attributes and methods.
* **But** we **do not** want persons “objects” to be created: a “person” in isolation does not make sense in our model, we only want to implement students or employees, not “persons”.

The mechanism used to obtain this behavior (being able to inherit from a class while disallowing instantiating it) is achieved using the abstract keyword.

## Example

Consider a (shortened) version of the example above. We start by implementing an *abstract* Person class:

abstract class Person  
{  
 public string Name { get; set; }  
 public abstract string Id { get; set; }  
}

Note that the Id property is *also* marked as abstract: this means that the derived class will have to re-implement this property’s setter and getter. Then, we can implement the Student and Employee classes by inheriting from the Person class:

using System;  
  
class Student : Person  
{  
 private string major;  
 private string id;  
 public override string Id  
 {  
 set  
 {  
 if (value[0] != 'S')  
 throw new ArgumentException(  
 "A student ID must start with an 'S'."  
 );  
 else  
 id = value;  
 }  
 get { return id; }  
 }  
}

using System;  
  
class Employee : Person  
{  
 private decimal hourlyPay;  
  
 public override string Id { get; set; }  
}

Note that the Employee does not need to add an attribute for Id since it is using automatic properties, but that Student does.

Using this code, the statement

Person test = new Person();

would return the error message “Cannot create an instance of the abstract type or interface ‘Person’”.

Furthermore, the following exemplifies the expected behavior:

﻿using System;  
  
class Program  
{  
 static void Main()  
 {  
 // Person test = new Person();  
 // Cannot create an instance of the abstract type or interface 'Person'  
 Employee Harley = new Employee();  
 Harley.Id = "E8190";  
  
 Student Morgan = new Student();  
 try  
 {  
 Morgan.Id = "E8194";  
 }  
 catch  
 {  
 Console.WriteLine(  
 "We cannot set the Id of a student to a string not starting with 'S'!"  
 );  
 }  
 Morgan.Id = "S8194";  
 }  
}

The statement Morgan.Id = "E8194"; will raise exception, but Morgan.Id = "S8194"; will execute without throwing an error.

## Additional Details: Abstract Properties and Methods

* As we’ve seen above with the Id property, not only classes can be marked as abstract.
* For abstract properties, using {get; set;}, only {get;} or only {set;} indicates if the derived class needs to implement both a setter and a getter, or only one of them.
* In addition to properties, *methods* can also be marked as abstract: in that case, their body need to be absent (not simply empty: missing).
  + For example, the Person class could also contain
  + public abstract string GenerateLogin();
  + to “force” any derived class to implement a GenerateLogin method that does not take any parameter and returns a string. The derived classes would need to implement a method that overrides the Person’s GenerateLogin method[[11]](#footnote-11):
  + public override string GenerateLogin(){  
     // Insert method body.  
    }
  + Note that an abstract method is implicitly a virtual method, as it *must* be overridden. Hence, no need to specify the virtual modifier.
* However, abstract attributes are not allowed.

## UML Class Diagram Representation

* An abstract class is represented by as a class with its name prefixed by <<Abstract>>, «Abstract», or with its name displayed in *italics*,
* An abstract method or property is represented as a usual, except that it is displayed in *italics*.
* Since, for example, Person’s GenerateLogin() method is to be overridden (it *has* to be, actually, since it is abstract), it is indicated again in the Student and Employee classes: this indicates that those method override the one they have inherited from the Person class.

A UML diagram for the Person ⇽ Student class (text version, image version, svg version)

# Interfaces

## Motivation

Imagine you want to represent a variety of devices, and comes up with the following UML diagram:

A UML diagram for the ComputingDevice ⇽ Abacus class (text version, image version, svg version)

Note that it is possible to gather that e.g., the Instructions() method in the Abacus class is overriding the Instructions() method in the ComputingDevice class because it has the same signature: this can be the case only because it is overriding the inherited abstract method.

Your abstract classes are “completely abstract”, in the sense that all of their properties and methods are abstract, but it serves your purpose just well:

* you do not want “ComputingDevices” to exist in isolation, but you want any class representing a computing device such as the [Abacus](https://en.wikipedia.org/wiki/Abacus), the [Pascaline](https://en.wikipedia.org/wiki/Pascal%27s_calculator) or the [Turing Tumble](https://en.wikipedia.org/wiki/Turing_Tumble) to have an *Instruction per seconds* property, and a method to display instructions.
* similarly, you want any “ElectronicalDevice” to have properties pertaining to their voltage and frequency, as well as a method to display a safety notice.

A class that is “completely abstract” actually forces you to enforce a series of constraints and is a good way of making sure that you are consistent e.g., with the naming of your methods, the accessibility of your properties, or the return type of your methods.

You implement it as follows:

abstract class ComputingDevice  
{  
 public abstract double IPS { get; set; }  
 public abstract void Instructions();  
}

using System;  
  
class Abacus : ComputingDevice  
{  
 private double ips;  
 public override double IPS  
 {  
 get { return ips; }  
 set  
 {  
 if (value < 0 || value > 1000)  
 throw new ArgumentException(  
 "This is not plausible"  
 );  
 else  
 ips = value;  
 }  
 }  
 public string Material { get; set; }  
  
 public Abacus(double ipsP, string materialP)  
 {  
 IPS = ipsP;  
 Material = materialP;  
 }  
  
 public override void Instructions()  
 {  
 Console.WriteLine(  
 "Refer to https://www.wikihow.com/Use-an-Abacus"  
 );  
 }  
}

abstract class ElectricalDevice  
{  
 public abstract int Voltage { get; set; }  
 public abstract int Frequency { get; set; }  
 public abstract void SafetyNotice();  
}

using System;  
  
class USWashingMachine : ElectricalDevice  
{  
 private int voltage;  
 public override int Voltage  
 {  
 get { return voltage; }  
 set  
 {  
 if (value < 110 || value > 220)  
 {  
 throw new ArgumentOutOfRangeException();  
 }  
 else  
 {  
 voltage = value;  
 }  
 }  
 }  
 private int frequency;  
 public override int Frequency  
 {  
 get { return frequency; }  
 set  
 {  
 if (value != 50 && value != 60)  
 {  
 throw new ArgumentOutOfRangeException();  
 }  
 else  
 frequency = value;  
 }  
 }  
  
 public USWashingMachine(int vP, int fP)  
 {  
 Voltage = vP;  
 Frequency = fP;  
 }  
  
 public override void SafetyNotice()  
 {  
 Console.WriteLine(  
 "Refer to https://www.energy.gov/sites/"  
 + "prod/files/2016/06/f32/"  
 + "NFPA\_DryerWasherSafetyTips.pdf"  
 );  
 }  
}

﻿using System;  
  
class Program  
{  
 static void Main()  
 {  
 Abacus test0 = new Abacus(1.5, "Wood");  
 test0.Instructions();  
 USWashingMachine test1 = new USWashingMachine(120, 50);  
 test1.SafetyNotice();  
 }  
}

[*(Download this code)*](https:/princomp.github.io/code/projects/Devices.zip)

Then, you would like to add a “Computer” class, but face an issue: classes can inherit only from one class directly, but of course a computer is *both* an electrical device **and** a computing device. A solution is to switch to *interfaces*.

## Explanations

Interfaces are completely abstract classes: they do not implement anything, they simply force classes inheriting from them (we actually say *that realizes them*) to implement certain features.

### In Diagram

Interfaces are prefixed by the «Interface» mention, and have all their properties and methods marked as abstract (so, in *italics*). A class can “inherits” from multiple interface (we say that it **realizes** multiple interfaces), and this is marked with an arrow with an open triangle end and a dashed line[[12]](#footnote-12).

A UML diagram for the ComputingDevice ◁┈ Computer class (text version, image version, svg version)

### An Implementation

Implementing such interfaces and their realization could be done as follows:

interface ComputingDevice  
{  
 double IPS { get; set; }  
 void Instructions();  
}

interface ElectricalDevice  
{  
 int Voltage { get; set; }  
 int Frequency { get; set; }  
 void SafetyNotice();  
}

using System;  
  
class Computer : ElectricalDevice, ComputingDevice  
{  
 private double ips;  
 public double IPS  
 {  
 get { return ips; }  
 set  
 {  
 if (value < 0)  
 throw new ArgumentException(  
 "This is not possible."  
 );  
 else  
 ips = value;  
 }  
 }  
 private int voltage;  
 public int Voltage  
 {  
 get { return voltage; }  
 set  
 {  
 if (value < 110 || value > 220)  
 {  
 throw new ArgumentOutOfRangeException();  
 }  
 else  
 {  
 voltage = value;  
 }  
 }  
 }  
 private int frequency;  
 public int Frequency  
 {  
 get { return frequency; }  
 set  
 {  
 if (value != 50 && value != 60)  
 {  
 throw new ArgumentOutOfRangeException();  
 }  
 else  
 frequency = value;  
 }  
 }  
  
 public Computer(double ipsP, int voltageP, int frequencyP)  
 {  
 IPS = ipsP;  
 Voltage = voltageP;  
 Frequency = frequencyP;  
 }  
  
 public void Instructions()  
 {  
 Console.WriteLine(  
 "Refer to your operating system manual."  
 );  
 }  
  
 public void SafetyNotice()  
 {  
 Console.WriteLine(  
 "Refer to your manufacturer website."  
 );  
 }  
}

﻿using System;  
  
class Program  
{  
 static void Main()  
 {  
 Computer test0 = new Computer(100000, 120, 50);  
 test0.SafetyNotice();  
 test0.Instructions();  
 }  
}

[*(Download this code)*](https:/princomp.github.io/code/projects/DevicesInterfaces.zip)

Note that

* in the ComputingDevice and ElectricalDevice,
  + abstract class has been replaced by interface,
  + there is no need for the abstract keyword (all is abstract already!),
  + there is no need for the public keyword (everything *has* to be public),
* in the Computer realization,
  + the class *realizes* two interfaces, simply separated by a comma:
  + Computer: ElectricalDevice, ComputingDevice
  + there is no need for the override keyword,

## A More Complicated Example

A UML diagram for the IAnimation ◁┈ Shape class (text version, image version, svg version)

[in this archive](https:/princomp.github.io/code/projects/Shape.zip)

# Introduction

Decisions are a constant occurrence in daily life. For instance consider an instructor teaching CSCI 1301. At the beginning of class the instructor may

* Ask if there are questions. If a student has a question, then the instructor will answer it, and ask again (“Anything else?”).
* When there are no more questions, the instructor will move on to the next step.
* If there is a quiz scheduled, the next step will be distributing the quiz.
* If there is no quiz scheduled or the quiz is complete (and collected), the instructor may introduce the lecture topic (“Today, we will be discussing Decisions and Decision Structures”) and start the class.
* etc.

This type of “branching” between multiple choices can be represented with an [activity diagram](https://en.wikipedia.org/wiki/Activity_diagram):

“An Activity Diagram on Teaching a Class”

In C#, we will express

* repetition (or “loops”) (“As long as there are questions…”) with the while, do and for keywords,
* branching (“If there is a quiz…”) with the if, if-else and switch keywords.

Both structures need a datatype to express the result of a decision (“Is it *true* that there are questions.”, or “Is it *false* that there is a quiz.”) called Booleans. Boolean values can be set with conditions, that can be composed in different ways using three operators (“and”, “or” and “not”). For example, “If today is a Monday or Wednesday, and it is not past 10:10 am, the class will also include a brief reminder about the upcoming exam.”

# Booleans

## Variables

We can store if something is true or false (“The user has reached the age of majority”, “The switch is on”, “The user is using Windows”, “This computer’s clock indicates that we are in the afternoon”, …) in a variable of type boolean, which is also known as a boolean *flag*. Note that true and false are the only possible two values for boolean variables: there is no third option!

We can declare, assign, initialize and display a boolean variable (flag) as with any other variable:

bool learning\_how\_to\_program = true;  
Console.WriteLine(learning\_how\_to\_program);

## Operations on Boolean Values

Boolean variables have only two possible values (true and false), but we can use three operations to construct more complex booleans:

1. “and” (&&, conjunction),
2. “or” (||, disjunction),
3. “not” (!, negation).

Each has the precise meaning described here:

1. the condition “A and B” is true if and only if A is true, and B is true,
2. “A or B” is false if and only if A is false, and B is false (that is, it takes only one to make their disjunction true),
3. “not A” is true if and only if A is false (that is, “not” “flips” the value it is applied to).

The expected results of these operations can be displayed in *truth tables*, as follows:

| Operation | Value |
| --- | --- |
| true && true | true |
| true && false | false |
| false && true | false |
| false && false | false |

| Operation | Value |
| --- | --- |
| true || true | true |
| true || false | true |
| false || true | true |
| false || false | false |

| Operation | Value |
| --- | --- |
| !true | false |
| !false | true |

These tables can also be written in 2-dimensions, as can be seen for [conjunction on wikipedia](https://en.wikipedia.org/wiki/Truth_table#Logical_conjunction_(AND)).

## Equality and Relational Operators

Boolean values can also be set through expressions, or tests, that “evaluate” a condition or series of conditions as true or false. For instance, you can write an expression meaning “variable myAge has the value 12” which will evaluate to true if the value of myAge is indeed 12, and to false otherwise. *To ease your understanding*, we will write “expression true” to indicate that “expression” evaluates to true below, but this is *not* part of C#’s syntax.

Here we use two kinds of operators:

* Equality operators test if two values (literal or variable) are the same. This works on all datatypes.
* Relational operators test if a value (literal or variable) is greater or smaller (strictly or largely) than an other value or variable.

Relational operators will be primarily used for numerical values.

## Equality Operators

In C#, we can test for equality and inequality using two operators, == and !=.

| Mathematical Notation | C# Notation | Example |
| --- | --- | --- |
|  | == | 3 == 4 false |
|  | != | 3!=4 true |

Note that testing for equality uses *two equal signs*: C# already uses a single equal sign for assignments (e.g. myAge = 12;), so it had to pick another notation! It is fairly common across programing languages to use a single equal sign for assignments and double equal for comparisons.

Writing a != b (“a is not the same as b”) is actually logically equivalent to writing !(a == b) (“it is not true that a is the same as b”), and both expressions are acceptable in C#.

We can test numerical values for equality, but actually any datatype can use those operators. Here are some examples for int, string, char and bool:

int myAge = 12;  
string myName = "Thomas";  
char myInitial = 'T';  
bool cs\_major = true;  
Console.WriteLine("My age is 12: " + (myAge == 12));  
Console.WriteLine("My name is Bob: " + (myName == "Bob"));  
Console.WriteLine("My initial is Q: " + (myInitial == 'Q'));  
Console.WriteLine("My major is Computer Science: " + cs\_major);

This program will display

My age is 12: True  
My name is Bob: False  
My initial is Q: False  
My major is Computer Science: True

Remember that C# is case-sensitive, and that applies to the equality operators as well: for C#, the string Thomas is not the same as the string thomas. This also holds for characters like a versus A.

Console.WriteLine("C# is case-sensitive for string comparison: " + ("thomas" != "Thomas"));  
Console.WriteLine("C# is case-sensitive for character comparison: " + ('C' != 'c'));  
Console.WriteLine("But C# does not care about 0 decimal values: " + (12.00 == 12));

This program will display:

C# is case-sensitive for string comparison: True  
C# is case-sensitive for character comparison: True  
But C# does not care about 0 decimal values: True

## Relational Operators

We can test if a value or a variable is greater than another, using the following *relational* operators.

| Mathematical Notation | C# Notation | Example |
| --- | --- | --- |
|  | > | 3 > 4 false |
|  | < | 3 < 4 true |
| or | >= | 3 >= 4 false |
| or | <= | 3 <= 4 true |

Relational operators can also compare char, but the order is a bit complex (you can find it explained, for instance, [in this stack overflow answer](https://stackoverflow.com/a/14967721/)).

## Precedence of Operators

All of the operators have a “precedence”, which is the order in which they are evaluated. The precedence is as follows:

| Operator |  |
| --- | --- |
| ! | is evaluated before |
| \*, /, and % | which are evaluated before |
| + and - | which are evaluated before |
| <, >, <=, and >= | which are evaluated before |
| == and != | which are evaluated before |
| && | which is evaluated before |
| || | which comes last. |

* Operators with higher precedence (higher in the table) are evaluated before operators with lower precedence (lower in the table). For instance, in an expression like 2\*3+4, 2\*3 will have higher precedence than 3+4, and thus be evaluated first: 2\*3+4 is to be read as (2\*3)+4 = 6 + 4 = 10 and *not* as 2\*(3+4) = 2\*7 = 14.
* Operators on the same row have equal precedence and are evaluated in the order they appear, from left to right: in 1-2+3, 1-2 will be evaluated before 2+3: 1-2+3 is to be read as (1-2)+3 = -1 + 3 = 2 and *not* as 1-(2+3) = 1-5 = 4.
* Forgetting about precedence can lead to errors that can be hard to debug: for instance, an expression such as ! 4 == 2 will give the error

The `!' operator cannot be applied to operand of type `int'

Since ! has a higher precedence than ==, C# first attempts to compute the result of !4, which corresponds to “not 4”. As negation (!) is an operation that can be applied only to booleans, this expression does not make sense and C# reports an error. The expression can be rewritten to change the order of evaluation by using parentheses, e.g. you can write !(4 == 2), which will correctly be evaluated to true.

# if

## if Statements

### Introduction

* Recall from a previous lecture (Booleans and Comparisons) that decision structures change the flow of code execution based on conditions
* Now that we know how to write conditions in C#, we can write decision structures
* Our first decision structure is the **if statement**, which executes a block of code *only if a condition is true*

### Example code with an if statement

Console.WriteLine("Enter your age");  
int age = int.Parse(Console.ReadLine());  
if (age >= 18)  
{  
 Console.WriteLine("You can vote!");  
}  
Console.WriteLine("Goodbye");

* After the keyword if is a condition, in parentheses: age >= 18
* On the next line after the if statement, the curly brace begins a code block. The code in this block is “controlled” by the if statement.
* If the condition age >= 18 is true, the code in the block (the WriteLine statement with the text “You can vote!”) gets executed, then execution proceeds to the next line (the WriteLine statement that prints “Goodbye”)
* If the condition age >= 18 is false, the code in the block gets *skipped*, and execution proceeds directly to the line that prints “Goodbye”
* The behavior of this program can be represented by this flowchart:
* “A flowchart representation of an if statement”
* Example interaction 1:
* Enter your age  
  20  
  You can vote!  
  Goodbye
* When the user enters “20”, the value 20 is assigned to the age variable, so the condition age >= 18 is true. This means the code inside the if statement’s block gets executed.
* Example interaction 2:
* Enter your age  
  17  
  Goodbye
* When the user enters “17”, the value 17 is assigned to the age variable, so the condition age >= 18 is false, and the if statement’s code block gets skipped.

### Syntax and rules for if statements

* Formally, the syntax for an if statement is this:
* if (<condition>)  
  {  
   <statements>  
  }
* The “condition” in parentheses can be any expression that produces a bool value, including all of the combinations of conditions we saw in the previous lecture (Booleans and Comparisons). It can even be a bool variable, since a bool variable “contains” a bool value.
* Note that there is no semicolon after the if (<condition>). It’s a kind of “header” for the following block of code, like a method header.
* The statements in the code block will be executed if the condition evaluates to true, or skipped if it evaluates to false
* If the code block contains only *one* statement, the curly braces can be omitted, producing the following syntax:
* if(<condition>)  
   <statement>
* For example, the if statement in our previous example could be written like this, since there was only one statement in the code block:
* if(age >= 18)  
   Console.WriteLine("You can vote!");  
  Console.WriteLine("Goodbye");
* Omitting the curly braces is slightly dangerous, though, because it makes it less obvious which line of code is controlled by the if statement. It is up to you, the programmer, to remember to indent the line after the if statement, and then de-indent the line after that; indentation is just a convention. Curly braces make it easier to see where the if statement starts and ends.

## if-else Statements

Example:

if(age >= 18)  
{  
 Console.WriteLine("You can vote!");  
}  
else  
{  
 Console.WriteLine("You are too young to vote");  
}  
Console.WriteLine("Goodbye");

* The **if-else statement** is a decision structure that chooses *which* block of code to execute, based on whether a condition is true or false
* In this example, the condition is age >= 18 again
* The first block of code (underneath the if) will be executed if the statement is true – the console will display “You can vote!”
* The *second* block of code, which comes after the keyword else, will be executed if the statement is *false* – so if the user’s age is less than 18, the console will display “You are too young to vote”
* Only one of these blocks of code will be executed; the other will be skipped
* After executing one of the two code blocks, execution continues at the next line after the else block, so in either case the console will next display “Goodbye”
* The behavior of this program can be represented by this flowchart:
* “A flowchart representation of an if-else statement”

### Syntax and comparison

* Formally, the syntax for an if-else statement is this:
* if (<condition>)  
  {  
   <statement block 1>  
  }  
  else  
  {  
   <statement block 2>  
  }
* As with the if statement, the condition can be anything that produces a bool value
* Note that there is no semicolon after the else keyword
* If the condition is true, the code in statement block 1 is executed (this is sometimes called the “if block”), and statement block 2 is skipped
* If the condition is false, the code in statement block 2 is executed (this is sometimes called the “else block”), and statement block 1 is skipped
* This is very similar to an if statement; the difference is what happens if the condition is false
  + With an if statement, the “if block” is executed if the condition is true, but *nothing happens* if the condition is false.
  + With an if-else statement, the code in the “else block” is executed if the condition is false, so something always happens - one of the two code blocks will get executed

## Nested if-else Statements

* If-else statements are used to change program flow based on a condition; they represent making a decision
* Sometimes decisions are more complex than a single yes/no question: once you know whether a certain condition is true or false, you then need to ask another question (check another condition) based on the outcome
* For example, we could improve our voting program to ask the user whether he/she is a US citizen, as well as his/her age. This means there are two conditions to evaluate, as shown in this flowchart:
* “A flowchart representation of the nested if-else statement”
  + First, the program should test whether the user is a citizen. If not, there is no need to check the user’s age, since he/she cannot vote anyway
  + If the user is a citizen, the program should then test whether the user is over 18 to determine if he/she is old enough to vote.

### Using nested if statements

* An if statement’s code block can contain any kind of statements, including another if statement
* Putting an if statement inside an if block represents making a sequence of decisions - once execution has reached the inside of an if block, your program “knows” that the if condition is true, so it can proceed to make the next decision
* For the voting example, we can implement the decision structure from the flowchart above with this code, assuming age is an int and usCitizen is a bool:
* if(usCitizen == true)  
  {  
   if(age >= 18)  
   {  
   Console.WriteLine("You can vote!");  
   }  
   else  
   {  
   Console.WriteLine("You are too young to vote");  
   }  
  }  
  else  
  {  
   Console.WriteLine("Sorry, only citizens can vote");  
  }  
  Console.WriteLine("Goodbye");
  + First, the program tests the condition usCitizen == true, and if it is true, the code in the first “if block” is executed
  + Within this if block is another if statement that tests the condition age >= 18. This represents checking the user’s age after determining that he/she is a US citizen - execution only reaches this second if statement if the first one evaluated to true. So “You can vote” is printed if both usCitizen == true and age >= 18
  + If the condition usCitizen == true is false, the if block is skipped and the else block is executed instead, so the entire inner if statement is never executed – the user’s age does not matter if he/she isn’t a citizen
  + Note that the condition usCitizen == true could also be expressed by just writing the name of the variable usCitizen (i.e., the if statement would be if(usCitizen)), because usCitizen is a bool variable. We do not need the equality comparison operator to test if it is true, because an if statement already tests whether its condition is true (and a bool variable by itself is a valid condition)
  + Note that indentation helps you match up an else block to its corresponding if block. The meaning of else depends on which if statement it goes with: the “outer” else will be executed if the condition usCitizen == true is false, while the “inner” else will be executed if the condition age >= 18 is false.
* Nested if statements do not need to be the *only* code in the if block; you can still write other statements before or after the nested if
* For example, we could change our voting program so that it only asks for the user’s age if he/she is a citizen:
* if(usCitizen == true)  
  {  
   Console.WriteLine("Enter your age");  
   int age = int.Parse(Console.ReadLine());  
   if(age >= 18)  
   {  
   Console.WriteLine("You can vote!");  
   }  
   else  
   {  
   Console.WriteLine("You are too young to vote");  
   }  
  }  
  else  
  {  
   Console.WriteLine("Sorry, only citizens can vote");  
  }  
  Console.WriteLine("Goodbye");

## if-else-if Statements

* Sometimes your program needs to test multiple conditions at once, and take different actions depending on which one is true
* Example: We want to write a program that tells the user which floor a ClassRoom object is on, based on its room number
  + If the room number is between 100 and 200 it is on the first floor; if it is between 200 and 300 it is on the second floor; if it is greater than 300 it is on the third floor
* There are 3 ranges of numbers to test, and 3 possible results, so we cannot do it with a single if-else statement

### If-else-if syntax

* An if-else-if statement looks like this:
* if(<condition 1>)  
  {  
   <statement block 1>  
  }  
  else if(<condition 2>)  
  {  
   <statement block 2>  
  }  
  else if(<condition 3>)  
  {  
   <statement block 3>  
  }  
  else  
  {  
   <statement block 4>  
  }
* Unlike an if statement, there are multiple conditions
* They are evaluated *in order*, top to bottom
* Just like with if-else, exactly one block of code will get executed
* If condition 1 is true, statement block 1 is executed, and everything else is skipped
* If condition 1 is false, statement block 1 is skipped, and execution proceeds to the first else if line; condition 2 is then evaluated
* If condition 2 is true, statement block 2 is executed, and everything else is skipped
  + Thus, statement block 2 is only executed if condition 1 is false *and* condition 2 is true
* Same process repeats for condition 3: If condition 2 is false, condition 3 is evaluated, and statement block 3 is either executed or skipped
* If *all* the conditions are false, the final else block (statement block 4) is executed

### Using if-else-if to solve the “floors problem”

* Assuming myRoom is a ClassRoom object, this code will display which floor it is on:
* if(myRoom.GetNumber() >= 300)  
  {  
   Console.WriteLine("Third floor");  
  }  
  else if(myRoom.GetNumber() >= 200)  
  {  
   Console.WriteLine("Second floor");  
  }  
  else if(myRoom.GetNumber() >= 100)  
  {  
   Console.WriteLine("First floor");  
  }  
  else  
  {  
   Console.WriteLine("Invalid room number");  
  }
* If the room number 300 or greater (e.g. 365), the first “if” block is executed, and the rest are skipped. The program prints “Third floor”
* If the room number is less than 300, the program continues to the line else if(myRoom.GetNumber() >= 200) and evaluates the condition
* If myRoom.GetNumber() >= 200 is true, it means the room number is between 200 and 299, and the program will print “Second floor.” Even though the condition only tests whether the room number is >= 200, this condition is only evaluated if the first one was false, so we know the room number must be < 300.
* If the second condition is false, the program continues to the line else if(myRoom.GetNumber() >= 100), evaluates the condition, and prints “First floor” if it is true.
* Again, the condition myRoom.GetNumber() >= 100 is only evaluated if the first two conditions have already been tested and turned out false, so we know the room number is less than 300 and less than 200.
* In the final else block, the program prints “Invalid room number” because this block is only executed if the room number is less than 100 (all three conditions were false).

### if-else-if with different conditions

* We often use if-else-if statements to test the same variable multiple times, but there is no requirement for the conditions to use the same variable
* An if-else-if statement can use several different variables, and its conditions can be completely unrelated, like this:
* int x;  
  if(myIntVar > 12)  
  {  
   x = 10;  
  }  
  else if(myStringVar == "Yes")  
  {  
   x = 20;  
  }  
  else if(myBoolVar)  
  {  
   x = 30;  
  }  
  else  
  {  
   x = 40;  
  }
* Note that the order of the else-if statements still matters, because they are evaluated top-to-bottom. If myIntVar is 15, it does not matter what values myStringVar or myBoolVar have, because the first if block (setting x to 10) will get executed.
* Example outcomes of executing this code (which value x is assigned) based on the values of myIntVar, myStringVar, and myBoolVar:

| myIntVar | myStringVar | myBoolVar | x |
| --- | --- | --- | --- |
| 12 | “Yes” | true | 20 |
| 15 | “Yes” | false | 10 |
| -15 | “yes” | true | 30 |
| 10 | “yes” | false | 40 |

### Comparing if-else-if and nested if statements

* Sometimes a nested if statement can be rewritten as an if-else-if statement
* This reduces the amount of indentation in your code, which makes it easier to read
* To convert a nested if statement to if-else-if, you’ll need to combine the conditions of the “outer” and “inner” if statements, using the logical operators
* A nested if statement inside an if block is testing whether the outer if’s condition is true *and* its own condition is true, so combine them with the && operator
* The else block of the inner if statement can be rewritten as an else if by combining the outer if’s condition with the *opposite* of the inner if’s condition, since “else” means “the condition is false.” We need to explicitly write down the “false condition” that is normally implied by else.
* For example, we can rewrite this nested if statement:
* if(usCitizen == true)  
  {  
   if(age >= 18)  
   {  
   Console.WriteLine("You can vote!");  
   }  
   else  
   {  
   Console.WriteLine("You are too young to vote");  
   }  
  }  
  else  
  {  
   Console.WriteLine("Sorry, only citizens can vote");  
  }
* as this if-else-if statement:
* if(usCitizen == true && age >= 18)  
  {  
   Console.WriteLine("You can vote!");  
  }  
  else if(usCitizen == true && age < 18)  
  {  
   Console.WriteLine("You are too young to vote");  
  }  
  else  
  {  
   Console.WriteLine("Sorry, only citizens can vote");  
  }
* Note that the else from the inner if statement becomes else if(usCitizen == true && age < 18) because we combined the outer if condition (usCitizen == true) with the opposite of the inner if condition (age >= 18).
* Not all nested if statements can be rewritten this way. If there is additional code in a block, other than the nested if statement, it is harder to convert it to an if-else-if
* For example, in this nested if statement:
* if(usCitizen == true)  
  {  
   Console.WriteLine("Enter your age");  
   int age = int.Parse(Console.ReadLine());  
   if(age >= 18)  
   {  
   Console.WriteLine("You can vote!");  
   }  
   else  
   {  
   Console.WriteLine("You are too young to vote");  
   }  
  }  
  else  
  {  
   Console.WriteLine("Sorry, only citizens can vote");  
  }  
  Console.WriteLine("Goodbye");
* the code that asks for the user’s age executes after the outer if condition is determined to be true, but before the inner if condition is tested. There would be nowhere to put this code if we tried to convert it to an if-else-if statement, since both conditions must be tested at the same time (in if(usCitizen == true && age >= 18)).
* On the other hand, any if-else-if statement can be rewritten as a nested if statement
* To convert an if-else-if statement to a nested if statement, rewrite each else if as an else block with a nested if statement inside it – like you’re splitting the “if” from the “else”
* This results in a lot of indenting if there are many else if lines, since each one becomes another nested if inside an else block
* For example, the “floors problem” could be rewritten like this:
* if(myRoom.GetNumber() >= 300)  
  {  
   Console.WriteLine("Third floor");  
  }  
  else  
  {  
   if(myRoom.GetNumber() >= 200)  
   {  
   Console.WriteLine("Second floor");  
   }  
   else  
   {  
   if(myRoom.GetNumber() >= 100)  
   {  
   Console.WriteLine("First floor");  
   }  
   else  
   {  
   Console.WriteLine("Invalid room number");  
   }  
   }  
  }

# Switch

## Switch Statements

### Multiple equality comparisons

* In some situations, your program will need to test if a variable is equal to one of several values, and perform a different action based on which value the variable matches
* For example, you have an int variable named month containing a month number, and want to convert it to a string with the name of the month. This means your program needs to take a different action depending on whether month is equal to 1, 2, 3, … or 12:
* “A flowchart representation of the mapping between month number and name”
* One way to do this is with a series of if-else-if statements, one for each possible value, like this:
* Console.WriteLine("Enter the month as a number between 1 and 12.");  
  int month = int.Parse(Console.ReadLine());  
  string monthName;  
  if(month == 1)  
  {  
   monthName = "January";  
  }  
  else if(month == 2)  
  {  
   monthName = "February";  
  }  
  else if(month == 3)  
  {  
   monthName = "March";  
  }  
  else if(month == 4)  
  {  
   monthName = "April";  
  }  
  else if(month == 5)  
  {  
   monthName = "May";  
  }  
  else if(month == 6)  
  {  
   monthName = "June";  
  }  
  else if(month == 7)  
  {  
   monthName = "July";  
  }  
  else if(month == 8)  
  {  
   monthName = "August";  
  }  
  else if(month == 9)  
  {  
   monthName = "September";  
  }  
  else if(month == 10)  
  {  
   monthName = "October";  
  }  
  else if(month == 11)  
  {  
   monthName = "November";  
  }  
  else if(month == 12)  
  {  
   monthName = "December";  
  }  
  else  
  {  
   monthName = "Error!"; // Invalid month  
  }  
  Console.WriteLine("The number " + month + " corresponds to the month " + monthName + ".")
* This code is very repetitive, though: every else if statement is almost the same, with only the number changing. The text “if(month ==” is copied over and over again.

### Syntax for switch statements

* A switch statement is a simpler, easier way to compare a single variable against multiple possible values
* It is written like this:
* switch (<variable name>)  
  {  
   case <value 1>:  
   <statement block 1>  
   break;  
   case <value 2>:  
   <statement block 2>  
   break;  
   …  
   default:  
   <statement block n>  
   break;  
  }
* First, the “header” of the switch statement names the variable that will be compared
* The “body” of the switch statement is enclosed in curly braces, and contains multiple case statements
* Each case statement gives a possible value the variable could have, and a block of statements to execute if the variable equals that value. Statement block 1 is executed if the variable is equal to value 1, statement block 2 is executed if the variable is equal to value 2, etc.
* The statement “block” within each case is **not** enclosed in curly braces, unlike if and else if blocks. Instead, it begins on the line after the case statement, and ends with the keyword break.
* The default statement is like the else statement: It defines code that gets executed if the variable does not match any of the values in the case statements.
* The values in each case statement must be **literals**, not variables, and they must be **unique** (you cannot write two case statements with the same value)

### Example switch statement

* This program has the same behavior as our previous example, but uses a switch statement instaed of an if-else-if statement:
* Console.WriteLine("Enter the month as a number between 1 and 12.");  
  int month = int.Parse(Console.ReadLine());  
  string monthName;  
  switch(month)  
  {  
   case 1:  
   monthName = "January";  
   break;  
   case 2:  
   monthName = "February";  
   break;  
   case 3:  
   monthName = "March";  
   break;  
   case 4:  
   monthName = "April";  
   break;  
   case 5:  
   monthName = "May";  
   break;  
   case 6:  
   monthName = "June";  
   break;  
   case 7:  
   monthName = "July";  
   break;  
   case 8:  
   monthName = "August";  
   break;  
   case 9:  
   monthName = "September";  
   break;  
   case 10:  
   monthName = "October";  
   break;  
   case 11:  
   monthName = "November";  
   break;  
   case 12:  
   monthName = "December";  
   break;  
   default:  
   monthName = "Error!"; // Invalid month  
   break;  
  }  
  Console.WriteLine("The number " + month + " corresponds to the month " + monthName + ".")
* Since the variable in the switch statement is month, each case statement means, effectively, if (month == <value>). For example, case 1: has the same effect as if (month == 1)
* The values in each case statement must be int literals, since month is an int
* The default statement has the same effect as the final else in the if-else-if statement: it contains code that will be executed if month did not match any of the values

### switch with multiple statements

* So far, our examples have used only one line of code in each case
* Unlike if-else, you do not need curly braces to put multiple lines of code in a case
* For example, imagine our “months” program needed to convert a month number to both a month name and a three-letter abbreviation. The switch would look like this:
* string monthName;  
  string monthAbbrev;  
  switch(month)  
  {  
   case 1:  
   monthName = "January";  
   monthAbbrev = "Jan";  
   break;  
   case 2:  
   monthName = "February";  
   monthAbbrev = "Feb";  
   break;  
   // and so on, with all the other months...  
  }
* The computer knows which statements are included in each case because of the break keyword. For the “1” case, the block of statements starts after case 1: and ends with the break; after monthAbbrev = "Jan";

### Intentionally omitting break

* Each block of code that starts with a case statement must end with a break statement; it will not automatically end at the next case statement
  + The case statement only defines where code execution *starts* when the variable matches a value (like an open {). The break statement defines where it *ends* (like a close }).
* However, there is one exception: A case statement with *no body* (code block) after it does not need a matching break
* If there is more than one value that should have the same behavior, you can write case statements for both values above a single block of code, with no break between them. If *either one* matches, the computer will execute that block of code, and then stop at the break statement.
* In a switch statement with this structure:
* switch(<variable>)  
  {  
   case <value 1>:  
   case <value 2>:  
   <statement block 1>  
   break;  
   case <value 3>:  
   case <value 4>:  
   <statement block 2>  
   break;  
   default:  
   <statement block 3>  
   break;  
  }
* The statements in block 1 will execute if the variable matches value 1 *or* value 2, and the statements in block 2 will execute if the variable matches value 3 *or* value 4.
* For example, imagine our program needs to tell the user which season the month is in. If the month number is 1, 2, or 3, the season is the same (winter), so we can combine these 3 cases. This code will correctly initialize the string season:
* switch(month)  
  {  
   case 1:  
   case 2:  
   case 3:  
   season = "Winter";  
   break;  
   case 4:  
   case 5:  
   case 6:  
   season = "Spring";  
   break;  
   case 7:  
   case 8:  
   case 9:  
   season = "Summer";  
   break;  
   case 10:  
   case 11:  
   case 12:  
   season = "Fall";  
   break;  
   default:  
   season = "Error!"  
   break;  
  }
* If month is equal to 1, execution will start at case 1:, but the computer will continue past case 2 and case 3 and execute season = "Winter". It will then stop when it reaches the break, so season gets the value “Winter”. Similarly, if month is equal to 2, execution will start at case 2:, and continue until the break statement, so season will also get the value “Winter”.
* This syntax allows switch statements to have conditions with a logical OR, equivalent to an if condition with an ||, like if(x == 1 || x == 2)
* For example, the “seasons” statement could also be written as an if-else-if with || operators, like this:
* if(month == 1 || month == 2 || month == 3)  
  {  
   season = "Winter";  
  }  
  else if(month == 4 || month == 5 || month == 6)  
  {  
   season = "Spring";  
  }  
  else if(month == 7 || month == 8 || month == 9)  
  {  
   season = "Summer";  
  }  
  else if(month == 10 || month == 11 || month == 12)  
  {  
   season = "Fall"  
  }  
  else  
  {  
   season = "Error!"  
  }

### Scope and switch

* In C#, the scope of a variable is defined by curly braces (recall that local variables defined in a method have a scope that ends with the } at the end of the method)
* Since the case statements in a switch do not have curly braces, they are all in the same scope: the one defined by the switch statement’s curly braces
* This means you cannot declare a “local” variable within a case statement – it will be in scope (visible) to all the other case statements
* For example, imagine you wanted to use a local variable named nextMonth to do some local computation within each case in the “months” program. This code will not work:
* switch(month)  
  {  
   case 1:  
   int nextMonth = 2;  
   monthName = "January";  
   // do something with nextMonth...  
   break;  
   case 2:  
   int nextMonth = 3;  
   monthName = "February";  
   // do something with nextMonth...  
   break;  
   //...  
  }
* The line int nextMonth = 3 would cause a compile error because a variable named nextMonth already exists – the one declared within case 1.

### Limitations of switch

* Not all if-else-if statements can be rewritten as switch statements
* switch can only test equality, so in general, only if statements whose condition uses == can be converted to switch
* For example, imagine we have a program that determines how much of a fee to charge a rental car customer based on the number of miles the car was driven. A variable named mileage contains the number of miles driven, and it is used in this if-else-if statement:
* decimal fee = 0;  
  if(mileage > 1000)  
  {  
   fee = 50.0M;  
  }  
  else if(mileage > 500)  
  {  
   fee = 25.0M;  
  }
* This if-else-if statement could not be converted to switch(mileage) because of the condition mileage > 1000. The switch statement would need to have a case for each number greater than 1000, which is infinitely many.

# While Loops

## Introduction to while loops

* There are two basic types of decision structures in all programming languages. We’ve just learned about the first, which is the “selection structure,” or if statement. This allows the program to choose whether or not to execute a block of code, based on a condition.
* The second basic decision structure is the loop, which allows the program to execute the same block of code repeatedly, and choose when to stop based on a condition.
* The **while statement** executes a block of code repeatedly, *as long as a condition is true*. You can also think of it as executing the code repeatedly *until a condition is false*

## Example code with a while loop

int counter = 0;  
while(counter <= 3)  
{  
 Console.WriteLine("Hello again!");  
 Console.WriteLine(counter);  
 counter++;  
}  
Console.WriteLine("Done");

* After the keyword while is a condition, in parentheses: counter <= 3
* On the next line after the while statement, the curly brace begins a code block. The code in this block is “controlled” by the while statement.
* The computer will repeatedly execute that block of code as long as the condition counter <= 3 is true
* Note that inside this block of code is the statement counter++, which increments counter by 1. So eventually, counter will be greater than 3, and the loop will stop because the condition is false.
* This program produces the following output:
* Hello again!  
  0  
  Hello again!  
  1  
  Hello again!  
  2  
  Hello again!  
  3  
  Done

## Syntax and rules for while loops

* Formally, the syntax for a while loop is this:
* while(<condition>)  
  {  
   <statements>  
  }
* Just like with an if statement, the condition is any expression that produces a bool value (including a bool variable by itself)
* When the computer encounters a while loop, it first evaluates the condition
* If the condition is false, the loop body (code block) is skipped, just like with an if statement
* If the condition is true, the loop body is executed
* After executing the loop body, the computer goes back to the while statement and evaluates the condition again to decide whether to execute the loop again
* Just like with an if statement, the curly braces can be omitted if the loop body is just one statement:
* while(<condition>)  
   <statement>
* Examining the example in detail
* When our example program executes, it initializes counter to 0, then it encounters the loop
* It evaluates the condition counter <= 0, which is true, so it executes the loop’s body. The program displays “Hello again!” and “0” on the screen.
* At the end of the code block (after counter++) the program returns to the while statement and evaluates the condition again. 1 is less than 3, so it executes the loop’s body again.
* This process repeats two more times, and the program displays “Hello again!” with “2” and “3”
* After displaying “3”, counter++ increments counter to 4. Then the program returns to the while statement and evaluates the condition, but counter <= 3 is false, so it skips the loop body and executes the last line of code (displaying “Done”)

## While loops may execute zero times

* You might think that a “loop” always repeats code, but nothing requires a while loop to execute at least once
* If the condition is false when the computer first encounters the loop, the loop body is skipped
* For example, if we initialize counter to 5 with our previous loop:
* int counter = 5;  
  while(counter <= 3)  
  {  
   Console.WriteLine("Hello again!");  
   Console.WriteLine(counter);  
   counter++;  
  }  
  Console.WriteLine("Done");
* The program will only display “Done,” because the body of the loop never executes. counter <= 3 is false the first time it is evaluated, so the program skips the code block and continues on the next line.

## Ensuring the loop ends

* If the loop condition is always true, the loop will never end, and your program will execute “forever” (until you forcibly stop it, or the computer shuts down)
* Obviously, if you use the value true for the condition, the loop will execute forever, like in this example:
* int number = 1;  
  while (true)  
   Console.WriteLine(number++);
* If you do not intend your loop to execute forever, you must ensure the statements in the loop’s body do something to *change a variable* in the loop condition, otherwise the condition will stay true
* For example, this loop will execute forever because the loop condition uses the variable counter, but the loop body does not change the value of counter:
* int counter = 0;  
  while(counter <= 3)  
  {  
   Console.WriteLine("Hello again!");  
   Console.WriteLine(counter);  
  }  
  Console.WriteLine("Done");
* This loop will also execute forever because the loop condition uses the variable num1, but the loop body changes the variable num2:
* int num1 = 0, num2 = 0;  
  while(num1 <= 5)  
  {  
   Console.WriteLine("Hello again!");  
   Console.WriteLine(num1);  
   num2++;  
  }  
  Console.WriteLine("Done");
* It’s not enough for the loop body to simply change the variable; it must change the variable in a way that will eventually *make the condition false*
  + For example, if the loop condition is counter <= 5, then the loop body must increase the value of counter so that it is eventually greater than 5
  + This loop will execute forever, even though it changes the right variable, because it changes the value in the wrong “direction”:
  + int number = 10;  
    while(number >= 0)  
    {  
     Console.WriteLine("Hello again!");  
     Console.WriteLine(number);  
     number++;  
    }
  + The loop condition checks to see whether number is 0, and number starts out at the value 10. But the loop body increments number, which only moves it further away from 0 in the positive direction. In order for this loop to work correctly, we need to *decrement* number in the loop body, so that eventually it will be less than 0.
  + This loop will execute forever, even though it uses the right variable in the loop body, because it multiplies the variable by 0:
  + int number = 0;  
    while (number <= 64)  
    {  
     Console.WriteLine(number);  
     number \*= 2;  
    }
  + Since number was initialized to 0, number \*= 2 does not actually change the value of number: . So the loop body will never make the condition number <= 64 false.

## Principles of writing a while loop

* When writing a while loop, ask yourself these questions about your program:
  1. When (under what conditions) do I want the loop to continue?
  2. When (under what conditions) do I want the loop to stop?
  3. How will the body of the loop bring it closer to its ending condition?
* This will help you think clearly about how to write your loop condition. You should write a condition (Boolean expression) that will be true in the circumstances described by (1), and false in the circumstances described by (2)
* Keep your answer to (3) in mind as you write the body of the loop, and make sure the actions in your loop’s body match the condition you wrote.

## While Loop With Complex Conditions

In the following example, a complex boolean expression is used in the *while* statement. The program gets a value and tries to parse it as an integer. If the value can not be converted to an integer, the program tries again, but not more than three times.

int c;  
string message;  
int count;  
bool res;  
  
Console.WriteLine("Please enter an integer.");  
message = Console.ReadLine();  
res = int.TryParse(message, out c);  
count = 0; // The user has 3 tries: count will be 0, 1, 2, and then we default.  
while (!res && count < 3)  
{  
 count++;  
 if (count == 3)  
 {  
 c = 1;  
 Console.WriteLine("I'm using the default value 1.");  
 }  
 else  
 {  
 Console.WriteLine("The value entered was not an integer.");  
 Console.WriteLine("Please enter an integer.");  
 message = Console.ReadLine();  
 res = int.TryParse(message, out c);  
 }  
}  
Console.WriteLine("The value is: " + c);

# do while

## Comparing while and if statements

* while and if are very similar: Both test a condition, execute a block of code if the condition is true, and skip the block of code if the condition is false
* There is only a difference if the condition is true: if statements only execute the block of code once if the condition is true, but while statements may execute the block of code multiple times if the condition is true
* Compare these snippets of code:

if(number < 3)  
{  
 Console.WriteLine("Hello!");  
 Console.WriteLine(number);  
 number++;  
}  
Console.WriteLine("Done");

and

while(number < 3)  
{  
 Console.WriteLine("Hello!");  
 Console.WriteLine(number);  
 number++;  
}  
Console.WriteLine("Done");

* If number is 4, then both will do the same thing: skip the block of code and display “Done”.
* If number is 2, both will also do the same thing: Display “Hello!” and “2”, then increment number to 3 and print “Done”.
* If number is 1, there is a difference: The if statement will only display “Hello!” once, but the while statement will display “Hello! 2” and “Hello! 3” before displaying “Done”

## Code duplication in while loops

* Since the while loop evaluates the condition before executing the code in the body (like an if statement), you sometimes end up duplicating code
* For example, consider an input-validation loop like the one we wrote for Item prices:

Console.WriteLine("Enter the item's price.");  
decimal price = decimal.Parse(Console.ReadLine());  
while(price < 0)  
{  
 Console.WriteLine("Invalid price. Please enter a non-negative price.");  
 price = decimal.Parse(Console.ReadLine());  
}  
Item myItem = new Item(desc, price);

* Before the while loop, we wrote two lines of code to prompt the user for input, read the user’s input, convert it to decimal, and store it in price
* In the body of the while loop, we also wrote two lines of code to prompt the user for input, read the user’s input, convert it to decimal, and store it in price
* The code before the while loop is necessary to give price an initial value, so that we can check it for validity in the while statement
* It would be nice if we could tell the while loop to execute the body first, and then check the condition

## Introduction to do-while

* The do-while loop executes the loop body **before** evaluating the condition
* Otherwise works the same as a while loop: If the condition is true, execute the loop body again; if the condition is false, stop the loop
* This can reduce repeated code, since the loop body is executed *at least once*
* Example:

decimal price;  
do  
{  
 Console.WriteLine("Please enter a non-negative price.");  
 price = decimal.Parse(Console.ReadLine());  
} while(price < 0);  
Item myItem = new Item(desc, price);

* The keyword do starts the code block for the loop body, but it does not have a condition, so the computer simply starts executing the body
* In the loop body, we prompt the user for input, read and parse the input, and store it in price
* The condition price < 0 is evaluated at the end of the loop body, so price has its initial value by the time the condition is evaluated
* If the user entered a valid price, and the condition is false, execution simply proceeds to the next line
* If the user entered a negative price (the condition is true), the computer returns to the beginning of the code block and executes the loop body again
* This has the same effect as the while loop: the user is prompted repeatedly until he/she enters a valid price, and the program can only reach the line Item myItem = new Item(desc, price) when price < 0 is false
* Note that the variable price must be declared before the do-while loop so that it is in scope after the loop. It would not be valid to declare price inside the body of the loop (e.g. on the line with decimal.Parse) because then its scope would be limited to inside that code block.

## Formal syntax and details of do-while

* A do-while loop is written like this:

do  
{  
 <statements>  
} while(<condition>);

* The do keyword does nothing, but it is required to indicate the start of the loop. You cannot just write a { by itself.
  + Unlike a while loop, a semicolon is required after while(<condition>)
  + It’s a convention to write the while keyword on the same line as the closing }, rather than on its own line as in a while loop
  + When the computer encounters a do-while loop, it first executes the body (code block), then evaluates the condition
  + If the condition is true, the computer jumps back to the do keyword and executes the loop body again
  + If the condition is false, execution continues to the next line after teh while keyword
  + If the loop body is only a single statement, you can omit the curly braces, but not the semicolon:
* do  
  <statement>  
  while(<condition>);

## do-while loops with multiple conditions

* We can combine both types of user-input validation in one loop: Ensuring the user entered a number (not some other string), and ensuring the number is valid. This is easier to do with a do-while loop:

decimal price;  
bool parseSuccess;  
do  
{  
 Console.WriteLine("Please enter a price (must be non-negative).");  
 parseSuccess = decimal.TryParse(Console.ReadLine(), out price);  
} while(!parseSuccess || price < 0);  
Item myItem = new Item(desc, price);

* There are two parts to the loop condition: (1) it should be true if the user did not enter a number, and (2) it should be true if the user entered a negative number.
* We combine these two conditions with || because either one, by itself, represents invalid input. Even if the user entered a valid number (which means !parseSuccess is false), the loop should not stop unless price < 0 is also false.
* Note that both variables must be declared before the loop begins, so that they are in scope both inside and outside the loop body

# Input Validation

## Valid and invalid data

* Depending on the purpose of your program, each variable might have a limited range of values that are “valid” or “good,” even if the data type can hold more
* For example, a decimal variable that holds a price (in dollars) should have a positive value, even though it is legal to store negative numbers in a decimal
* Consider the Item class, which represents an item sold in a store. It has a price attribute that should only store positive values:

class Item  
{  
 private string description;  
 private decimal price;  
  
 public Item(string initDesc, decimal initPrice)  
 {  
 description = initDesc;  
 price = initPrice;  
 }  
  
 public decimal GetPrice()  
 {  
 return price;  
 }  
  
 public void SetPrice(decimal p)  
 {  
 price = p;  
 }  
  
 public string GetDescription()  
 {  
 return description;  
 }  
  
 public void SetDescription(string desc)  
 {  
 description = desc;  
 }  
}

* When you write a program that constructs an Item from literal values, you (the programmer) can make sure you only use positive prices. However, if you construct an Item based on input provided by the user, you cannot be certain that the user will follow directions and enter a valid price:

Console.WriteLine("Enter the item's description");  
string desc = Console.ReadLine();  
Console.WriteLine("Enter the item's price (must be positive)");  
decimal price = decimal.Parse(Console.ReadLine());  
Item myItem = new Item(desc, price);

In this code, if the user enters a negative number, the myItem object will have a negative price, even though that does not make sense.

* One way to guard against “bad” user input values is to use an if statement or a conditional operator, as we saw in the previous lecture (Switch and Conditional), to provide a default value if the user’s input is invalid. In our example with Item, we could add a conditional operator to check whether price is negative before providing it to the Item constructor:

decimal price = decimal.Parse(Console.ReadLine());  
Item myItem = new Item(desc, (price >= 0) ? price : 0);

In this code, the second argument to the Item constructor is the result of the conditional operator, which will be 0 if price is negative.

* You can also put the conditional operator inside the constructor, to ensure that an Item with an invalid price can never be created. If we wrote this constructor inside the Item class:

public Item(string initDesc, decimal initPrice)  
{  
 description = initDesc;  
 price = (initPrice >= 0) ? initPrice : 0;  
}

then the instantiation new Item(desc, price) would never be able to create an object with a negative price. If the user provides an invalid price, the constructor will ignore their value and initialize the price instance variable to 0 instead.

## Ensuring data is valid with a loop

* Another way to protect your program from “bad” user input is to check whether the data is valid as soon as the user enters it, and prompt him/her to re-enter the data if it is not valid
* A while loop is the perfect fit for this approach: you can write a loop condition that is true when the user’s input is *invalid*, and ask the user for input in the body of the loop. This means your program will repeatedly ask the user for input until he/she enters valid data.
* This code uses a while loop to ensure the user enters a non-negative price:

Console.WriteLine("Enter the item's price.");  
decimal price = decimal.Parse(Console.ReadLine());  
while(price < 0)  
{  
 Console.WriteLine("Invalid price. Please enter a non-negative price.");  
 price = decimal.Parse(Console.ReadLine());  
}  
Item myItem = new Item(desc, price);

* The condition for the while loop is price < 0, which is true when the user’s input is invalid
* If the user enters a valid price the first time, the loop will not execute at all – remember that a while loop will skip the code block if the condition is false
* Inside the loop’s body, we ask the user for input again, and assign the result of decimal.Parse to the same price variable we use in the loop condition. This is what ensures that the loop will end: the variable in the condition gets changed in the body.
* If the user still enters a negative price, the loop condition will be true, and the body will execute again (prompting them to try again)
* If the user enters a valid price, the loop condition will be false, so the program will proceed to the next line and instantiate the Item
* Note that the *only* way for the program to “escape” from the while loop is for the user to enter a valid price. This means that new Item(desc, price) is guaranteed to create an Item with a non-negative price, even if we did not write the constructor that checks whether initPrice >= 0. On the next line of code after the end of a while loop, you can be certain that the loop’s condition is false, otherwise execution would not have reached that point.

## Ensuring the user enters a number with TryParse

* Another way that user input might be invalid: When asked for a number, the user could enter something that is not a number
* The Parse methods we have been using assume that the string they are given (in the argument) is a valid number, and produce a run-time error if it is not
* For example, this program will crash if the user enters “hello” instead of a number:

Console.WriteLine("Guess a number"):  
int guess = int.Parse(Console.ReadLine());  
if(guess == favoriteNumber)  
{  
 Console.WriteLine("That's my favorite number!");  
}

* Each built-in data type has a **TryParse method** that will *attempt* to convert a string to a number, but will not crash (produce a run-time error) if the conversion fails. Instead, TryParse indicates failure by returning the Boolean value false
* The TryParse method is used like this:

string userInput = Console.ReadLine();  
int intVar;  
bool success = int.TryParse(userInput, out intVar);

* The first parameter is a string to be parsed (userInput)
* The second parameter is an **out parameter**, and it is the name of a variable that will be assigned the result of the conversion. The keyword out indicates that a method parameter is used for *output* rather than *input*, and so the variable you use for that argument will be changed by the method.
* The return type of TryParse is bool, not int, and the value returned indicates whether the input string was successfully parsed
* If the string userInput contains an integer, TryParse will assign that integer value to intVar and return true (which gets assigned to success)
* If the string userInput does not contain an integer, TryParse will assign 0 to intVar and return false (which gets assigned to success)
* Either way, the program will not crash, and intVar will be assigned a new value
* The other data types have TryParse methods that are used the same way. The code will follow this general format:

bool success = <numeric datatype>.TryParse(<string to convert>, out <numeric variable to store result>)

Note that the variable you use in the out parameter must be the same type as the one whose TryParse method is being called. If you write decimal.TryParse, the out parameter must be a decimal variable.

* A more complete example of using TryParse:

Console.WriteLine("Please enter an integer");  
string userInput = Console.ReadLine();  
int intVar;  
bool success = int.TryParse(userInput, out intVar);  
if(success)  
{  
 Console.WriteLine($"The value entered was an integer: {intVar}");  
}  
else  
{  
 Console.WriteLine($"\"{userInput}\" was not an integer");  
}  
Console.WriteLine(intVar);

* The TryParse method will attempt to convert the user’s input to an int and store the result in intVar
* If the user entered an integer, success will be true, and the program will display “The value entered was an integer:” followed by the user’s value
* If the user entered some other string, success will be false, and the program will display a message indicating that it was not an integer
* Either way, intVar will be assigned a value, so it is safe to write Console.WriteLine(intVar). This will display the user’s input if the user entered an integer, or “0” if the user did not enter an integer.
* Just like with Parse, you can use Console.ReadLine() itself as the first argument rather than a string variable. Also, you can declare the output variable within the out parameter, instead of on a previous line. So we can read user input, declare an int variable, and attempt to parse the user’s input all on one line:

bool success = int.TryParse(Console.ReadLine(), out int intVar);

* You can use the return value of TryParse in a while loop to keep prompting the user until they enter valid input:

Console.WriteLine("Please enter an integer");  
bool success = int.TryParse(Console.ReadLine(), out int number);  
while(!success)  
{  
 Console.WriteLine("That was not an integer, please try again.");  
 success = int.TryParse(Console.ReadLine(), out number);  
}

* The loop condition should be true when the user’s input is *invalid*, so we use the negation operator ! to write a condition that is true when success is false
* Each time the loop body executes, both success and number are assigned new values by TryParse

# The foreach Loop

* When writing a for loop that accesses each element of an array once, you will end up writing code like this:
* for(int i = 0; i < myArray.Length; i++)  
  {  
   <do something with myArray[i]>;  
  }
* In some cases, this code has unnecessary repetition: If you are not using the counter i for anything other than an array index, you still need to declare it, increment it, and write the condition with myArray.Length
* The **foreach loop** is a shortcut that allows you to get rid of the counter variable and the loop condition. It has this syntax:
* foreach(<type> <variableName> in <arrayName>)  
  {  
   <do something with variable>  
  }
  + The loop will repeat exactly as many times as there are elements in the array
  + On each iteration of the loop, the variable will be assigned the next value from the array, in order
  + The variable must be the same type as the array
* For example, this loop accesses each element of homeworkGrades and computes their sum:
* int sum = 0;  
  foreach(int grade in homeworkGrades)  
  {  
   sum += grade;  
  }
  + The variable grade is declared with type int since homeworkGrades is an array of int
  + grade has a scope limited to the body of the loop, just like the counter variable i
  + In successive iterations of the loop grade will have the value homeworkGrades[0], then homeworkGrades[1], and so on, through homeworkGrades[homeworkGrades.Length - 1]
* A foreach loop is **read-only** with respect to the array: The loop’s variable cannot be used to *change* any elements of the array. This code will result in an error:
* foreach(int grade in homeworkGrades)  
  {  
   grade = int.Parse(Console.ReadLine());  
  }

# For Loops

## Counter-controlled loops

* Previously, when we learned about loop vocabulary, we looked at counter-controlled while loops
* Although counter-controlled loops can perform many different kinds of actions in the body of the loop, they all use very similar code for managing the counter variable
* Two examples of counter-controlled while loops:
* int i = 0;  
  while(i < 10)  
  {  
   Console.WriteLine($"{i}");  
   i++;  
  }  
  Console.WriteLine("Done");
* int num = 1, total = 0;  
  while(num <= 25)  
  {  
   total += num;  
   num++;  
  }  
  Console.WriteLine($"The sum is {total}");
* Notice that in both cases, we’ve written the same three pieces of code:
  + Initialize a counter variable (i or num) before the loop starts
  + Write a loop condition that will become false when the counter reaches a certain value (i < 10 or num <= 25)
  + Increment the counter variable at the end of each loop iteration, as the last line of the body

## for loop example and syntax

* This for loop does the same thing as the first of the two while loops above:
* for(int i = 0; i < 10; i++)  
  {  
   Console.WriteLine($"{i}");  
  }  
  Console.WriteLine("Done");
  + The for statement actually contains 3 statements in 1 line; note that they are separated by semicolons
  + The code to initialize the counter variable has moved inside the for statement, and appears first
  + Next is the loop condition, i < 10
  + The third statement is the increment operation, i++, which no longer needs to be written at the end of the loop body
* In general, for loops have this syntax:
* for(<initialization>; <condition>; <update>)  
  {  
   <statements>  
  }
  + The initialization statement is executed once, when the program first reaches the loop. This is where you declare and initialize the counter variable.
  + The condition statement works exactly the same as a while loop’s condition statement: Before executing the loop’s body, the computer checks the condition, and skips the body (ending the loop) if it is false.
  + The update statement is code that will be executed each time the loop’s body *ends*, before checking the condition again. You can imagine that it gets inserted right before the closing } of the loop body. This is where you increment the counter variable.
* Examining the example in detail
  + When the computer executes our example for loop, it first creates the variable i and initializes it to 0
  + Then it evaluates the condition i < 10, which is true, so it executes the loop’s body. The computer displays “0” in the console.
  + At the end of the code block for the loop’s body, the computer executes the update code, i++, and changes the value of i to 1.
  + Then it returns to the beginning of the loop and evaluates the condition again. Since it is still true, it executes the loop body again.
  + This process repeats several more times. On the last iteration, i is equal to 9. The computer displays “9” on the screen, then increments i to 10 at the end of the loop body.
  + The computer returns to the for statement and evaluates the condition, but i < 10 is false, so it skips the loop body and proceeds to the next line of code. It displays “Done” in the console.

## Limitations and Pitfalls of Using for Loops

### Scope of the for loop’s variable

* When you declare a counter variable in the for statement, its scope is limited to *inside* the loop
* Just like method parameters, it is as if the variable declaration happened just inside the opening {, so it can only be accessed inside that code block
* This means you cannot use a counter variable after the end of the loop. This code will produce a compile error:
* int total = 0;  
  for(int count = 0; count < 10; count++)  
  {  
   total += count;  
  }  
  Console.WriteLine($"The average is {(double) total / count}");
* If you want to use the counter variable after the end of the loop, you must declare it *before* the loop
* This means your loop’s initialization statement will need to assign the variable its starting value, but not declare it
* This code works correctly, since count is still in scope after the end of the loop:
* int total = 0;  
  int count;  
  for(count = 0; count < 10; count++)  
  {  
   total += count;  
  }  
  Console.WriteLine($"The average is {(double) total / count}");

### Accidentally re-declaring a variable

* If your for loop declares a new variable in its initialization statement, it cannot have the same name as a variable already in scope
* If you want your counter variable to still be in scope after the end of the loop, you cannot also declare it in the for loop. This is why we had to write for(count = 0... instead of for(int count = 0... in the previous example: the name count was already being used.
* Since counter variables often use short, common names (like i or count), it is more likely that you’ll accidentally re-use one that’s already in scope
* For example, you might have a program with many for loops, and in one of them you decide to declare the counter variable outside the loop because you need to use it after the end of the loop. This can cause an error in a different for loop much later in the program:
* int total = 0;  
  int i;  
  for(i = 0; i < 10; i++)  
  {  
   total += i;  
  }  
  Console.WriteLine($"The average is {(double) total / i}");  
  // Many more lines of code  
  // ...  
  // Some time later:  
  for(int i = 0; i < 10; i++)  
  {  
   Console.WriteLine($"{i}");  
  }
* The compiler will produce an error on the second for loop, because the name “i” is already being used.
* On the other hand, if all of your for loops declare their variables inside the for statement, it is perfectly fine to reuse the same variable name. This code does not produce any errors:
* int total = 0;  
  for(int i = 0; i < 10; i++)  
  {  
   total += i;  
  }  
  Console.WriteLine($"The total is {total}");  
  // Some time later:  
  for(int i = 0; i < 10; i++)  
  {  
   Console.WriteLine($"{i}");  
  }

### Accidentally double-incrementing the counter

* Now that you know about for loops, you may want to convert some of your counter-controlled while loops to for loops
* Remember that in a while loop the counter must be incremented in the loop body, but in a for loop the increment is part of the loop’s header
* If you just convert the header of the loop and leave the body the same, you will end up incrementing the counter *twice* per iteration. For example, if you convert this while loop:
* int i = 0;  
  while(i < 10)  
  {  
   Console.WriteLine($"{i}");  
   i++;  
  }  
  Console.WriteLine("Done");
* to this for loop:
* for(int i = 0; i < 10; i++)  
  {  
   Console.WriteLine($"{i}");  
   i++;  
  }  
  Console.WriteLine("Done");
* it will not work correctly, because i will be incremented by both the loop body and the loop’s update statement. The loop will seem to “skip” every other value of i.

## More Ways to use for Loops

### Complex condition statements

* The condition in a for loop can be any expression that results in a bool value
* If the condition compares the counter to a variable, the number of iterations depends on the variable. If the variable comes from user input, the loop is also user-controlled, like in this example:
* Console.WriteLine("Enter a positive number.");  
  int numTimes = int.Parse(Console.ReadLine());  
  for(int c = 0; c < numTimes; c++)  
  {  
   Console.WriteLine("\*\*\*\*\*\*\*\*\*\*");  
  }
* The condition can compare the counter to the result of a method call. In this case, the method will get called on every iteration of the loop, since the condition is re-evaluated every time the loop returns to the beginning. For example, in this loop:
* for(int i = 1; i <= (int) myItem.GetPrice(); i++)  
  {  
   Console.WriteLine($"${i}");  
  }
* the GetPrice() method of myItem will be called every time the condition is evaluated.

### Complex update statements

* The update statement can be anything, not just an increment operation
* For example, you can write a loop that only processes the even numbers like this:
* for(int i = 0; i < 19; i += 2)  
  {  
   Console.WriteLine($"{i}");  
  }
* You can write a loop that decreases the counter variable on every iteration, like this:
* for(int t = 10; t > 0; t--)  
  {  
   Console.Write($"{t}...");  
  }  
  Console.WriteLine("Liftoff!");

### Complex loop bodies

* The loop body can contain more complex statements, including other decision structures
* if statements can be nested inside for loops, and they will be evaluated again on every iteration
* For example, in this program:
* for(int i = 0; i < 8; i++)  
  {  
   if(i % 2 == 0)  
   {  
   Console.WriteLine("It's my turn");  
   }  
   else  
   {  
   Console.WriteLine("It's your turn");  
   }  
   Console.WriteLine("Switching players...");  
  }
* On even-numbered iterations, the computer will display “It’s my turn” followed by “Switching players…”, and on odd-numbered iterations the computer will display “It’s your turn” followed by “Switching players…”
* for loops can contain other for loops. This means the “inner” loop will execute all of its iterations each time the “outer” loop executes one iteration.
* For example, this program prints a multiplication table:
* for(int r = 0; r < 11; r++)  
  {  
   for(int c = 0; c < 11; c++)  
   {  
   Console.Write($"{r} x {c} = {r \* c} \t");  
   }  
   Console.Write("\n");  
  }
* The outer loop prints the rows of the table, while the inner loop prints the columns. On a single iteration of the outer for loop (i.e. when r = 2), the inner for loop executes its body 11 times, using values of c from 0 to 10. Then the computer executes the Console.Write("\n") to print a newline before the next “row” iteration.

### Combining for and while loops

* while loops are good for sentinel-controlled loops or user-input validation, and for loops are good for counter-controlled loops
* This program asks the user to enter a number, then uses a for loop to print that number of asterisks on a single line:
* string userInput;  
  do  
  {  
   Console.WriteLine("Enter a positive number, or \"Q\" to stop");  
   userInput = Console.ReadLine();  
   int inputNum;  
   int.TryParse(userInput, out inputNum);  
   if(inputNum > 0)  
   {  
   for(int c = 0; c < inputNum; c++)  
   {  
   Console.Write("\*");  
   }  
   Console.WriteLine();  
   }  
  } while(userInput != "Q");
  + The sentinel value “Q” is used to end the program, so the outer while loop repeats until the user enters this value
  + Once the user enters a number, that number is used in the condition for a for loop that prints asterisks using Console.Write(). After the for loop ends, we use Console.WriteLine() with no argument to end the line (print a newline).
  + Since the user could enter either a letter or a number, we need to use TryParse to convert the user’s input to a number
  + If TryParse fails (because the user entered a non-number), inputNum will be assigned the value 0. This is also an invalid value for the loop counter, so we do not need to check whether TryParse returned true or false. Instead, we simply check whether inputNum is valid (greater than 0) before executing the for loop, and skip the for loop entirely if inputNum is negative or 0.

# Loop Vocabulary

Variables and values can have multiple roles, but it is useful to mention three different roles in the context of loops:

Counter

Variable that is incremented every time a given event occurs.

int i = 0; // i is a counter  
while (i < 10){  
 Console.WriteLine($"{i}");  
 i++;  
}

Sentinel Value

A special value that signals that the loop needs to end.

Console.WriteLine("Give me a string.");  
string ans = Console.ReadLine();  
while (ans != "Quit") // The sentinel value is "Quit".  
{  
 Console.WriteLine("Hi!");  
 Console.WriteLine("Enter \"Quit\" to quit, or anything else to continue.");  
 ans = Console.ReadLine();  
}

Accumulator

Variable used to keep the total of several values.

int i = 0, total = 0;  
while (i < 10){  
 total += i; // total is the accumulator.  
 i++;  
}  
  
Console.WriteLine($"The sum from 0 to {i} is {total}.");

We can have an accumulator and a sentinel value at the same time:

Console.WriteLine("Enter a number to sum, or \"Done\" to stop and print the total.");  
string enter = Console.ReadLine();  
int sum = 0;  
while (enter != "Done")  
{  
 sum += int.Parse(enter);  
 Console.WriteLine("Enter a number to sum, or \"Done\" to stop and print the total.");  
 enter = Console.ReadLine();  
}  
Console.WriteLine($"Your total is {sum}.");

You can have counter, accumulator and sentinel values at the same time:

int a = 0;  
int sum = 0;  
int counter = 0;  
Console.WriteLine("Enter an integer, or N to quit.");  
string entered = Console.ReadLine();  
while (entered != "N") // Sentinel value  
{  
 a = int.Parse(entered);  
 sum += a; // Accumulator  
 Console.WriteLine("Enter an integer, or N to quit.");  
 entered = Console.ReadLine();  
 counter++; // counter  
}  
Console.WriteLine($"The average is {sum / (double)counter}");

We can distinguish between three “flavors” of loops (that are not mutually exclusive):

Sentinel controlled loop

The exit condition tests if a variable has (or is different from) a *specific value*.

User controlled loop

The number of iterations depends on the *user*.

Count controlled loop

The number of iterations depends on a *counter*.

Note that a user-controlled loop can be sentinel-controlled (that is the example we just saw), but also count-controlled (“Give me a value, and I will iterate a task that many times”).

# Combining Classes and Decision Structures

Now that we have learned about decision structures, we can revisit classes and methods. Decision structures can make our methods more flexible, useful, and functional.

## Using if Statements with Methods

There are several ways we can use if-else and if-else-if statements with methods:

* For input validation in setters and properties
* For input validation in constructors
* With Boolean parameters to change a method’s behavior
* Inside a method to evaluate instance variables

### Setters with Input Validation

* Recall that getters and setters are used to implement **encapsulation**: an object’s attributes (instance variables) can only be changed by code in that object’s class
* For example, this Item class (which represents an item for sale in a store) has two attributes, a price and a description. Code outside the Item class (e.g. in the Main method) can only change these attributes by calling SetPrice and SetDescription
* class Item  
  {  
   private string description;  
   private decimal price;  
    
   public Item(string initDesc, decimal initPrice)  
   {  
   description = initDesc;  
   price = initPrice;  
   }  
    
   public decimal GetPrice()  
   {  
   return price;  
   }  
    
   public void SetPrice(decimal p)  
   {  
   price = p;  
   }  
    
   public string GetDescription()  
   {  
   return description;  
   }  
    
   public void SetDescription(string desc)  
   {  
   description = desc;  
   }  
  }
* Right now, it is possible to set the price to any value, including a negative number, but a negative price does not make sense. If we add an if statement to SetPrice, we can check that the new value is a valid price before changing the instance variable:
* public void SetPrice(decimal p)  
  {  
   if(p >= 0)  
   {  
   price = p;  
   }  
   else  
   {  
   price = 0;  
   }  
  }
  + If the parameter p is less than 0, we do not assign it to price; instead we set price to the nearest valid value, which is 0.
  + Since code outside the Item class cannot access price directly, this means it is now impossible to give an item a negative price: If your code calls myItem.SetPrice(-90m), myItem’s price will be 0, not -90.
* Alternatively, we could write a setter that simply ignores invalid values, instead of changing the instance variable to the “nearest valid” value
* For example, in the Rectangle class, the length and width attributes must also be non-negative. We could write a setter for width like this:
* public void SetWidth(int newWidth)  
  {  
   if(newWidth >= 0)  
   {  
   width = newWidth  
   }  
  }
  + This means if myRectangle has a width of 6, and your code calls myRectangle.SetWidth(-18), then myRectangle will still have a width of 6.
* A setter with input validation is a good example of where a conditional operator can be useful. We can write the SetPrice method with one line of code using a conditional operator:
* public void SetPrice(decimal p)  
  {  
   price = (p >= 0) ? p : 0;  
  }
* The instance variable price is assigned to the result of the conditional operator, which is either p, if p is a valid price, or 0, if p is not a valid price.
* If you have a class that uses properties instead of getters and setters, the same kind of validation can be added to the set component of a property
  + For example, the “price” attribute could be implemented with a property like this:
  + public decimal Price  
    {  
     get  
     {  
     return price;  
     }  
     set  
     {  
     price = value;  
     }  
    }
  + We can add an if statement or a conditional operator to the set accessor to ensure the price is not set to a negative number:
  + public decimal Price  
    {  
     get  
     {  
     return price;  
     }  
     set  
     {  
     price = (value >= 0) ? value : 0;  
     }  
    }
* If a class’s attributes have a more limited range of valid values, we might need to write a more complex condition in the setter. For example, consider the Time class:
* class Time  
  {  
   private int hours;  
   private int minutes;  
   private int seconds;  
  }
* In a Time object, hours can be any non-negative number, but minutes and seconds must be between 0 and 59 for it to represent a valid time interval
* The SetMinutes method can be written as follows:
* public void SetMinutes(int newMinutes)  
  {  
   if(newMinutes >= 0 && newMinutes < 60)  
   {  
   minutes = newMinutes;  
   }  
   else if(newMinutes >= 60)  
   {  
   minutes = 59;  
   }  
   else  
   {  
   minutes = 0;  
   }  
  }
  + If the parameter newMinutes is between 0 and 59 (both greater than or equal to 0 and less than 60), it is valid and can be assigned to minutes
  + If newMinutes is 60 or greater, we set minutes to the largest possible value, which is 59
  + If newMinutes is less than 0, we set minutes to the smallest possible value, which is 0
  + Note that we need an if-else-if statement because there are two different ways that newMinutes can be invalid (too large or too small) and we need to distinguish between them. When the condition newMinutes >= 0 && newMinutes < 60 is false, it could either be because newMinutes is less than 0 or because newMinutes is greater than 59. The else if clause tests which of these possibilities is true.

### Constructors with Input Validation

* A constructor’s job is to initialize the object’s instance variables, so it is very similar to a “setter” for all the instance variables at once
* If the constructor uses parameters to initialize the instance variables, it can use if statements to ensure the instance variables are not initialized to “bad” values
* Returning to the Item class, this is how we could write a 2-argument constructor that initializes the price to 0 if the parameter initPrice is not a valid price:
* public Item(string initDesc, decimal initPrice)  
  {  
   description = initDesc;  
   price = (initPrice >= 0) ? initPrice : 0;  
  }
* With both this constructor and the SetPrice method we wrote earlier, we can now guarantee that it is impossible for an Item object to have a negative price. This will make it easier to write a large program that uses many Item objects without introducing bugs: the program cannot accidentally reduce an item’s price below 0, and it can add up the prices of all the items and be sure to get the correct answer.
* Recall the ClassRoom class from an earlier lecture, which has a room number as one of its attributes. If we know that no classroom building has more than 3 floors, then the room number must be between 100 and 399. The constructor for ClassRoom could check that the room number is valid using an if-else-if statement, as follows:
* public ClassRoom(string buildingParam, int numberParam)  
  {  
   building = buildingParam;  
   if(numberParam >= 400)  
   {  
   number = 399;  
   }  
   else if(numberParam < 100)  
   {  
   number = 100;  
   }  
   else  
   {  
   number = numberParam;  
   }  
  }
  + Here, we have used similar logic to the SetMinutes method of the Time class, but with the conditions tested in the opposite order
  + First, we check if numberParam is too large (greater than 399), and if so, initialize number to 399
  + Then we check if numberParam is too small (less than 100), and if so, initialize number to 100
  + If both of these conditions are false, it means numberParam is a valid room number, so we can initialize number to numberParam
* The Time class also needs a constructor that checks if its parameters are within a valid range, since both minutes and seconds must be between 0 and 59
* However, with this class we can be “smarter” about the way we handle values that are too large. If a user attempts to construct a Time object with a value of 0 hours and 75 minutes, the constructor could “correct” this to 1 hour and 15 minutes and initialize the Time object with these equivalent values. In other words, this code:
* Time classTime = new Time(0, 75, 0);  
  Console.WriteLine($"{classTime.GetHours()} hours, {classTime.GetMinutes()} minutes");
* should produce the output “1 hours, 15 minutes”, not “0 hours, 59 minutes”
* Here’s a first attempt at writing the Time constructor:
* public Time(int hourParam, int minuteParam, int secondParam)  
  {  
   hours = (hourParam >= 0) ? hourParam : 0;  
   if(minuteParam >= 60)  
   {  
   minutes = minuteParam % 60;  
   hours += minuteParam / 60;  
   }  
   else if(minuteParam < 0)  
   {  
   minutes = 0;  
   }  
   else  
   {  
   minutes = minuteParam;  
   }  
   if(secondParam >= 60)  
   {  
   seconds = secondParam % 60;  
   minutes += secondParam / 60;  
   }  
   else if(secondParam < 0)  
   {  
   seconds = 0;  
   }  
   else  
   {  
   seconds = secondParam;  
   }  
  }
  + First, we initialize hours using hourParam, unless hourParam is negative. There is no upper limit on the value of hours
  + If minuteParam is 60 or greater, we perform an integer division by 60 and add the result to hours, while using the remainder after dividing by 60 to initialize minutes. This separates the value into a whole number of hours and a remaining, valid, number of minutes. Since hours has already been initialized, it is important to use += (to add to the existing value).
  + Similarly, if secondParam is 60 or greater, we divide it into a whole number of minutes and a remaining number of seconds, and add the number of minutes to minutes
  + With all three parameters, any negative value is replaced with 0
* This constructor has an error, however: If minuteParam is 59 and secondParam is 60 or greater, minutes will be initialized to 59, but then the second if-else-if statement will increase minutes to 60. There are two ways we can fix this problem.
  + One is to add a nested if statement that checks if minutes has been increased past 59 by secondParam:
  + public Time(int hourParam, int minuteParam, int secondParam)  
    {  
     hours = (hourParam >= 0) ? hourParam : 0;  
     if(minuteParam >= 60)  
     {  
     minutes = minuteParam % 60;  
     hours += minuteParam / 60;  
     }  
     else if(minuteParam < 0)  
     {  
     minutes = 0;  
     }  
     else  
     {  
     minutes = minuteParam;  
     }  
     if(secondParam >= 60)  
     {  
     seconds = secondParam % 60;  
     minutes += secondParam / 60;  
     if(minutes >= 60)  
     {  
     hours += minutes / 60;  
     minutes = minutes % 60;  
     }  
     }  
     else if(secondParam < 0)  
     {  
     seconds = 0;  
     }  
     else  
     {  
     seconds = secondParam;  
     }  
    }
  + Another is to use the AddMinutes method we have already written to increase minutes, rather than the += operator, because this method ensures that minutes stays between 0 and 59 and increments hours if necessary:
  + public Time(int hourParam, int minuteParam, int secondParam)  
    {  
     hours = (hourParam >= 0) ? hourParam : 0;  
     if(minuteParam >= 60)  
     {  
     AddMinutes(minuteParam);  
     }  
     else if(minuteParam < 0)  
     {  
     minutes = 0;  
     }  
     else  
     {  
     minutes = minuteParam;  
     }  
     if(secondParam >= 60)  
     {  
     seconds = secondParam % 60;  
     AddMinutes(secondParam / 60);  
     }  
     else if(secondParam < 0)  
     {  
     seconds = 0;  
     }  
     else  
     {  
     seconds = secondParam;  
     }  
    }
  + Note that we can also use AddMinutes in the first if statement, since it will perform the same integer division and remainder operations that we originally wrote for minuteParam.

### Boolean Parameters

* When writing a method, we might want a single method to take one of two different actions depending on some condition, instead of doing the same thing every time. In this case we can declare the method with a bool parameter, whose value represents whether the method should (true) or should not (false) have a certain behavior.
* For example, in the Room class we wrote in lab, we wrote two separate methods to compute the area of the room: ComputeArea() would compute and return the area in meters, while ComputeAreaFeet() would compute and return the area in feet. Instead, we could write a single method that computes the area in either feet or meters depending on a parameter:
* public double ComputeArea(bool useMeters)  
  {  
   if(useMeters)  
   return length \* width;  
   else  
   return GetLengthFeet() \* GetWidthFeet();  
  }
  + If the useMeters parameter is true, this method acts like the original ComputeArea method and returns the area in meters
  + If the useMeters parameter is false, this method acts like ComputeAreaFeet and returns the area in feet
  + We can use the method like this:
  + Console.WriteLine("Compute area in feet (f) or meters (m)?");  
    char userChoice = char.Parse(Console.ReadLine());  
    if(userChoice == 'f')  
    {  
     Console.WriteLine($"Area: {myRoom.ComputeArea(false)}");  
    }  
    else if(userChoice == 'm')  
    {  
     Console.WriteLine($"Area: {myRoom.ComputeArea(true)}");  
    }  
    else  
    {  
     Console.WriteLine("Invalid choice");  
    }
  + Regardless of whether the user requests feet or meters, we can call the same method. Instead of calling ComputeAreaFeet() when the user requests the area in feet, we call ComputeArea(false)
  + Note that the bool argument to ComputeArea can be any expression that results in a Boolean value, not just true or false. This means that we can actually eliminate the if statement from the previous example:
  + Console.WriteLine("Compute area in feet (f) or meters (m)?");  
    char userChoice = char.Parse(Console.ReadLine());  
    bool wantsMeters = userChoice == 'm';  
    Console.WriteLine($"Area: {myRoom.ComputeArea(wantsMeters)}");
  + The expression userChoice == 'm' is true if the user has requested to see the area in meters. Instead of testing this expression in an if statement, we can simply use it as the argument to ComputeArea – if the expression is true, we should call ComputeArea(true) to get the area in meters.
* Constructors are also methods, and we can add Boolean parameters to constructors as well, if we want to change their behavior. Remember that the parameters of a constructor do not need to correspond directly to instance variables that the constructor will initialize.
* For example, in the lab we wrote two different constructors for the Room class: one that would interpret its parameters as meters, and one that would interpret its parameters as feet. Since parameter names (“meters” or “feet”) are not part of a method’s signature, we ensured the two constructors had different signatures by omitting the “name” parameter from the feet constructor.
  + Meters constructor:
  + public Room(double lengthMeters, double widthMeters, string initName)
  + Feet constructor:
  + public Room(double lengthFeet, double widthFeet)
  + The problem with this approach is that the feet constructor cannot initialize the name of the room; if we gave it a string parameter for the room name, it would have the same signature as the meters constructor.
  + Using a Boolean parameter, we can write a single constructor that accepts either meters or feet, and is equally capable of initializing the name attribute in both cases:
  + public Room(double lengthP, double widthP, string nameP, bool meters)  
    {  
     if(meters)  
     {  
     length = lengthP;  
     width = widthP;  
     }  
     else  
     {  
     length = lengthP \* 0.3048;  
     width = widthP \* 0.3048;  
     }  
     name = nameP;  
    }
  + If the parameter meters is true, this constructor interprets the length and width parameters as meters (acting like the previous “meters constructor”), but if meters is false, this constructor interprets the length and width parameters as feet (acting like the previous “feet constructor”).

### Ordinary Methods Using if

* Besides enhancing our “setter” methods, we can also use if statements to write other methods that change their behavior based on conditions
* For example, we could add a GetFloor method to ClassRoom that returns a string describing which floor the classroom is on. This looks very similar to the example if-else-if statement we wrote in a previous lecture, but inside the ClassRoom class rather than in a Main method:
* public string GetFloor()  
  {  
   if(number >= 300)  
   {  
   return "Third floor";  
   }  
   else if(number >= 200)  
   {  
   return "Second floor";  
   }  
   else if(number >= 100)  
   {  
   return "First floor";  
   }  
   else  
   {  
   return "Invalid room";  
   }  
  }
  + Now we can replace the if-else-if statement in the Main method with a single statement: Console.WriteLine(myRoom.GetFloor());
* We can add a MakeCube method to the Prism class that transforms the prism into a cube by “shrinking” two of its three dimensions, so that all three are equal to the smallest dimension. For example, if myPrism is a prism with length 4, width 3, and depth 6, myPrism.MakeCube() should change its length and depth to 3.
* public void MakeCube()  
  {  
   if(length <= width && length <= depth)  
   {  
   width = length;  
   depth = length;  
   }  
   else if(width <= length && width <= depth)  
   {  
   length = width;  
   depth = width;  
   }  
   else  
   {  
   length = depth;  
   width = depth;  
   }  
  }
  + This if-else-if statement first checks to see if length is the smallest dimension, and if so, sets the other two dimensions to be equal to length
  + Similarly, if width is the smallest dimension, it sets both other dimensions to width
  + No condition is necessary in the else clause, because one of the three dimensions must be the smallest. If the first two conditions are false, depth must be the smallest dimension.
  + Note that we need to use <= in both comparisons, not <: if length is equal to width, but smaller than depth, we should still set all dimensions to be equal to length

### Boolean Instance Variables

* A class might need a bool instance variable if it has an attribute that can only be in one of two states, e.g. on/off, feet/meters, on sale/not on sale
* For example, we can add an instance variable called “taxable” to the Item class to indicate whether or not the item should have sales tax added to its price at checkout. The UML diagram for Item with this instance variable would look like this:
* A UML diagram for the Item class (text version, image version, svg version)
  + Note that the “getter” for a Boolean variable is conventionally named with a word like “Is” or “Has” rather than “Get”
  + We will add a constant named SALES\_TAX to the Item class to store the sales tax rate that should be applied if the item is taxable. The sales tax rate is not likely to change during the program’s execution, but it is better to store it in a named variable instead of writing the same literal value (e.g. 0.08m) every time we want to compute a total price with tax.
* The instance variables and constructor for Item now look like this:
* class Item  
  {  
   private string description;  
   private decimal price;  
   private bool taxable  
   public const decimal SALES\_TAX = 0.08m;  
    
   public Item(string initDesc, decimal initPrice, bool isTaxable)  
   {  
   description = initDesc;  
   price = (initPrice >= 0) ? initPrice : 0;  
   taxable = isTaxable;  
   }  
  ...  
  }
* We can use this instance variable in a Main method to compute the final price of an Item based on whether or not it is taxable:
* Item myItem = new Item("Blue Polo Shirt", 19.99m, true);  
  decimal totalPrice = myItem.GetPrice();  
  if(myItem.isTaxable())  
  {  
   totalPrice = totalPrice + (totalPrice \* Item.SALES\_TAX);  
  }  
  Console.WriteLine($"Final price: {totalPrice:C}");
* However, if we were writing a program that handled large numbers of items, we might find it tedious to write this if statement every time. To make it easier to compute the “real” (with tax) price of an item, we could instead modify the GetPrice() method to automatically include sales tax if applicable:
* public decimal GetPrice()  
  {  
   if(taxable)  
   return price + (price \* SALES\_TAX);  
   else  
   return price;  
  }
* Now, myItem.GetPrice() will return the price with tax if the item is taxable, so our Main method can simply use myItem.GetPrice() as the total price without needing to check myItem.isTaxable().

## Using while Loops with Classes

There are several ways that while loops are useful when working with classes and methods:

* To validate input before calling a method
* Inside a method, to interact with the user
* Inside a method, to take repeated action based on the object’s attributes
* To control program behavior based on the return value of a method

### Input Validation with Objects

* As we have seen in a previous section (Loops and Input Validation), while loops can be used with the TryParse method to repeatedly prompt the user for input until he/she enters a valid value
* This is a useful technique to use before initializing an object’s attributes with user-provided data
* For example, the length and width of a Rectangle object should be non-negative integers. If we want to create a Rectangle with a length and width provided by the user, we can use a while loop for each attribute to ensure the user enters valid values before constructing the Rectangle.
* int length, width;  
  bool isInt;  
  do  
  {  
   Console.WriteLine("Enter a positive length");  
   isInt = int.TryParse(Console.ReadLine(), out length);  
  } while(!isInt || length < 0);  
  do  
  {  
   Console.WriteLine("Enter a positive width");  
   isInt = int.TryParse(Console.ReadLine(), out width);  
  } while(!isInt || width < 0);  
  Rectangle myRectangle = new Rectangle(length, width);
  + Each loop asks the user to enter a number, and repeats if the user enters a non-integer (TryParse returns false) or enters a negative number (length or width is less than 0).
  + Note that we can re-use the bool variable isInt to contain the return value of TryParse in the second loop, since it would otherwise have no purpose or meaning after the first loop ends.
  + After both loops have ended, we know that length and width are sensible values to use to construct a Rectangle
* Similarly, we can use while loops to validate user input before calling a non-constructor method that takes arguments, such as Rectangle’s Multiply method or Item’s SetPrice method
* For example, if a program has an already-initialized Item object named myItem and wants to use SetPrice to change its price to a user-provided value, we can use a while loop to keep prompting the user for input until he/she enters a valid price.
* bool isNumber;  
  decimal newPrice;  
  do  
  {  
   Console.WriteLine($"Enter a new price for {myItem.GetDescription()}");  
   isNumber = decimal.TryParse(Console.ReadLine(), out newPrice);  
  } while(!isNumber || newPrice < 0);  
  myItem.SetPrice(newPrice);
  + Like with our previous example, the while loop’s condition will be true if the user enters a non-numeric string, or a negative value. Thus the loop will only stop when newPrice contains a valid price provided by the user.
  + Although it is “safe” to pass a negative value as the argument to SetPrice, now that we added an if statement to SetPrice, it can still be useful to write this while loop
  + The SetPrice method will use a default value of 0 if its argument is negative, but it will not alert the user that the price they provided is invalid or give them an opportunity to provide a new price
* The ComputeArea method that we wrote earlier for the Room class demonstrates another situation where it is useful to write a while loop before calling a method
  + Note that in the version of the code that passes the user’s input directly to the ComputeArea method, instead of using an if-else-if statement, there is nothing to ensure the user enters one of the choices “f” or “m”:
  + Console.WriteLine("Compute area in feet (f) or meters (m)?");  
    char userChoice = char.Parse(Console.ReadLine());  
    Console.WriteLine($"Area: {myRoom.ComputeArea(userChoice == 'm')}");
  + This means that if the user enters a multiple-letter string the program will crash (char.Parse throws an exception if its input string is larger than one character), and if the user enters a letter other than “m” the program will act as if he/she entered “f”
  + Instead, we can use TryParse and a while loop to ensure that userChoice is either “f” or “m” and nothing else
  + bool validChar;  
    char userChoice;  
    do  
    {  
     Console.WriteLine("Compute area in feet (f) or meters (m)?");  
     validChar = char.TryParse(Console.ReadLine(), out userChoice);  
    } while(!validChar || !(userChoice == 'f' || userChoice == 'm'));  
    Console.WriteLine($"Area: {myRoom.ComputeArea(userChoice == 'm')}");
  + This loop will prompt the user for input again if TryParse returns false, meaning he/she did not enter a single letter. It will also prompt again if the user’s input was not equal to 'f' or 'm'.
  + Note that we needed to use parentheses around the expression !(userChoice == 'f' || userChoice == 'm') in order to apply the ! operator to the entire “OR” condition. This represents the statement “it is not true that userChoice is equal to ‘f’ or ‘m’.” We could also write this expression as (userChoice != 'f' && userChoice != 'm'), which represents the equivalent statement “userChoice is not equal to ‘f’ and also not equal to ‘m’.”

### Using Loops Inside Methods

* A class’s methods can contain while loops if they need to execute some code repeatedly. This means that when you call such a method, control will not return to the Main program until the loop has stopped.
* Reading input from the user, validating it, and using it to set the attributes of an object is a common task in the programs we have been writing. If we want to do this for several objects, we might end up writing many very similar while loops in the Main method. Instead, we could write a method that will read and validate user input for an object’s attribute every time it is called.
  + For example, we could add a method SetLengthFromUser to the Rectangle class:
  + public void SetLengthFromUser()  
    {  
     bool isInt;  
     do  
     {  
     Console.WriteLine("Enter a positive length");  
     isInt = int.TryParse(Console.ReadLine(), out length);  
     } while(!isInt || length < 0);  
    }
  + This method is similar to a setter, but it has no parameters because its only input comes from the user
  + The while loop is just like the one we wrote before constructing a Rectangle in a previous example, except the out parameter of TryParse is the instance variable length instead of a local variable in the Main method
  + TryParse will assign the user’s input to the length instance variable when it succeeds, so by the time the loop ends, the Rectangle’s length has been set to the user-provided value
  + Assuming we wrote a similar method SetWidthFromUser() (substituting width for length in the code), we would use these methods in the Main method like this:
  + Rectangle rect1 = new Rectangle();  
    Rectangle rect2 = new Rectangle();  
    rect1.SetLengthFromUser();  
    rect1.SetWidthFromUser();  
    rect2.SetLengthFromUser();  
    rect2.SetWidthFromUser();
  + After executing this code, both rect1 and rect2 have been initialized with length and width values the user entered.
* Methods can also contain while loops that are not related to validating input. A method might use a while loop to repeat an action several times based on the object’s instance variables.
  + For example, we could add a method to the Rectangle class that will display the Rectangle object as a rectangle of asterisks on the screen:
  + public void DrawInConsole()  
    {  
     int counter = 1;  
     while(counter <= width \* length)  
     {  
     Console.Write(" \* ");  
     if(counter % width == 0)  
     {  
     Console.WriteLine();  
     }  
     counter++;  
     }  
    }
  + This while loop prints a number of asterisks equal to the area of the rectangle. Each time it prints width of them on the same line, it adds a line break with WriteLine().

### Using Methods to Control Loops

* Methods can return Boolean values, as we showed previously in the section on Boolean instance variables
* Other code can use the return value of an object’s method in the loop condition of a while loop, so the loop is controlled (in part) by the state of the object
* For example, recall the Time class, which stores hours, minutes, and seconds in instance variables.
  + In a previous example we wrote a GetTotalSeconds() method to convert these three instance variables into a single value:
  + public int GetTotalSeconds()  
    {  
     return hours \* 60 \* 60 + minutes \* 60 + seconds;  
    }
  + We can now write a method ComesBefore that compares two Time objects:
  + public bool ComesBefore(Time otherTime)  
    {  
     return GetTotalSeconds() < otherTime.GetTotalSeconds();  
    }
  + This method will return true if the calling object (i.e. this object) represents a smaller amount of time than the other Time object passed as an argument
  + Since it returns a Boolean value, we can use the ComesBefore method to control a loop. Specifically, we can write a program that asks the user to enter a Time value that is smaller than a specified maximum, and use ComesBefore to validate the user’s input.
  + Time maximumTime = new Time(2, 45, 0);  
    Time userTime;  
    do  
    {  
     Console.WriteLine($"Enter a time less than {maximumTime}");  
     int hours, minutes, seconds;  
     do  
     {  
     Console.Write("Enter the hours: ");  
     } while(!int.TryParse(Console.ReadLine(), out hours));  
     do  
     {  
     Console.Write("Enter the minutes: ");  
     } while(!int.TryParse(Console.ReadLine(), out minutes));  
     do  
     {  
     Console.Write("Enter the seconds: ");  
     } while(!int.TryParse(Console.ReadLine(), out seconds));  
     userTime = new Time(hours, minutes, seconds);  
    } while(!userTime.ComesBefore(maximumTime));  
    //At this point, userTime is valid Time object
  + Note that there are while loops to validate each number the user inputs for hours, minutes, and seconds, as well as an outer while loop that validates the Time object as a whole.
  + The outer loop will continue until the user enters values that make userTime.ComesBefore(maximumTime) return true.

## Examples

### The Room Class

The class and its associated Main method presented [in this archive](https:/princomp.github.io/code/projects/Room.zip) show how you can use classes, methods, constructors and decision structures all in the same program. It also exemplifies how a method can take *an object* as a parameter with InSameBuilding.

The corresponding UML diagram is:

A UML diagram for the Room class (text version, image version, svg version)

### The Loan Class

Similarly, this class and its associated Main method show how you can use classes, methods, constructors, decision structures, and user input validation all in the same program. [This lab](https:/princomp.github.io/labs/ValidatingInput) asks you to add the user input validation code, and you can download the following code [in this archive](https:/princomp.github.io/code/projects/LoanCalculator.zip).

﻿/\*  
 \* Application program for the "Loan" class.  
 \* This program gathers from the user all the information needed  
 \* to create a "proper" Loan object.  
\*/  
  
using System;  
  
class Program  
{  
 static void Main()  
 {  
 Console.WriteLine("What is your name?");  
 string name = Console.ReadLine();  
  
 Console.WriteLine(  
 "Do you want a loan for an Auto (A, a), a House (H, h), or for some Other (O, o) reason?"  
 );  
 char type = Console.ReadKey().KeyChar; // This part of the code reads \*a char\* from the user.  
 // We haven't studied it, but it's pretty straightforward.  
 Console.WriteLine();  
  
 /\*  
 \* The part of the code that follows  
 \* does the convertion from the character  
 \* to the corresponding string.  
 \* We could have a method in the Loan  
 \* class that does it for us, but  
 \* we'll just do it "by hand" here  
 \* for simplicity.  
 \*/  
 string typeOfLoan;  
  
 if (type == 'A' || type == 'a')  
 {  
 type = 'a';  
 typeOfLoan = "an auto";  
 }  
 else if (type == 'H' || type == 'h')  
 {  
 type = 'h';  
 typeOfLoan = "a house";  
 }  
 else  
 {  
 type = 'o';  
 typeOfLoan = "some other reason";  
 }  
  
 // We display the information back to the user, and ask the next question:  
 Console.WriteLine(  
 $"{name}, you need money for {typeOfLoan}, great.\nWhat is your current credit score?"  
 );  
 int cscore = int.Parse(Console.ReadLine());  
  
 Console.WriteLine("How much do you need, total?");  
 decimal need = decimal.Parse(Console.ReadLine());  
  
 Console.WriteLine("What is your down payment?");  
 decimal down = decimal.Parse(Console.ReadLine());  
  
 Loan myLoan = new Loan(name, type, cscore, need, down);  
 Console.WriteLine(myLoan);  
 }  
}

﻿/\*  
 \* "Loan" class.  
 \* This class helps primarily in computing  
 \* an APR based on information provided from the user.  
 \* A ToString method is provided.  
 \*/  
using System;  
  
class Loan  
{  
 private string name; // For the name of the loan holder.  
 private char type; // For the type ('a'uto, 'h'ouse or 'o'ther) of the loan  
 private int cscore; // For the credit score.  
 private decimal amount; // For the amount of money loaned.  
 private decimal rate; // For the A.P.R., the interest rate.  
  
 /\*  
 \* Our constuctor will compute the amount and the rate  
 \* based on the information given as arguments.  
 \* The name, type and credit score will simply be given as arguments.  
 \*/  
 public Loan(  
 string nameP,  
 char typeP,  
 int cscoreP,  
 decimal needP,  
 decimal downP  
 )  
 {  
 name = nameP;  
 type = typeP;  
 cscore = cscoreP;  
 if (cscore < 421)  
 {  
 Console.WriteLine(  
 "Sorry, we can't accept your application."  
 );  
 amount = -1;  
 rate = -1;  
 }  
 else  
 {  
 amount = needP - downP;  
  
 switch (type)  
 {  
 case ('a'):  
 rate = .05M;  
 break;  
  
 case ('h'):  
 if (cscore > 600 && amount < 1000000M)  
 rate = .03M;  
 else  
 rate = .04M;  
 break;  
  
 case ('o'):  
 if (cscore > 650 || amount < 10000M)  
 rate = .07M;  
 else  
 rate = .09M;  
 break;  
 }  
 }  
 }  
  
 public override string ToString()  
 {  
 string typeName = "";  
 switch (type)  
 {  
 case ('a'):  
 typeName = "an auto";  
 break;  
  
 case ('h'):  
 typeName = "a house";  
 break;  
 case ('o'):  
 typeName = "another reason";  
 break;  
 }  
 return "Dear "  
 + name  
 + $", you borrowed {amount:C} at {rate:P} for "  
 + typeName  
 + ".";  
 }  
}

# Break and continue

## Conditional iteration

* Sometimes, you want to write a loop that will skip some iterations if a certain condition is met
* For example, you may be writing a for loop that iterates through an array of numbers, but you only want to use *even* numbers from the array
* One way to accomplish this is to nest an if statement inside the for loop that checks for the desired condition. For example:

int sum = 0;  
for(int i = 0; i < myArray.Length; i++)  
{  
 if(myArray[i] % 2 == 0)  
 {  
 Console.WriteLine(myArray[i]);  
 sum += myArray[i];  
 }  
}

Since the entire body of the for loop is contained within an if statement, the iterations where myArray[i] is odd will skip the body and do nothing.

## Skipping iterations with continue

* The continue keyword provides another way to conditionally skip an iteration of a loop
* When the computer encounters a continue; statement, it immediately returns to the beginning of the current loop, skipping the rest of the loop body
* Then it executes the update statement (if the loop is a for loop) and checks the loop condition again
* A continue; statement inside an if statement will end the current iteration only if that condition is true
* For example, this code will skip the odd numbers in myArray and use only the even numbers:

int sum = 0;  
for(int i = 0; i < myArray.Length; i++)  
{  
 if(myArray[i] % 2 != 0)  
 continue;  
 Console.WriteLine(myArray[i]);  
 sum += myArray[i];  
}

If myArray[i] is odd, the computer will execute the continue statement and immediately start the next iteration of the loop. This means that the rest of the loop body (the other two statements) only gets executed if myArray[i] is even.

* Using a continue statement instead of putting the entire body within an if statement can reduce the amount of indentation in your code, and it can sometimes make your code’s logic clearer.

## Loops with multiple end conditions

* More advanced loops may have multiple conditions that affect whether the loop should continue
* Attempting to combine all of these conditions in the loop condition (i.e. the expression after while) can make the loop more complicated
* For example, consider a loop that processes user input, which should end either when a sentinel value is encountered or when the input is invalid. This loop ends if the user enters a negative number (the sentinel value) or a non-numeric string:

int sum = 0, userNum = 0;  
bool success = true;  
while(success && userNum >= 0)  
{  
 sum += userNum;  
 Console.WriteLine("Enter a positive number to add it. "  
 + "Enter anything else to stop.");  
 success = int.TryParse(Console.ReadLine(), out userNum);  
}  
Console.WriteLine($"The sum of your numbers is {sum}");

* The condition success && userNum >= 0 is true if the user entered a valid number that was not negative
* In order to write this condition, we needed to declare the extra variable success to keep track of the result of int.TryParse
* We cannot use the condition userNum > 0, hoping to take advantage of the fact that if TryParse fails it assigns its out parameter the value 0, because 0 is a valid input the user could give

## Ending the loop with break

* The break keyword provides another way to write an additional end condition
* When the computer encounters a break; statement, it immediately ends the loop and proceeds to the next statement after the loop body
* This is the same break keyword we used in switch statements
* In both cases it has the same meaning: stop execution here and skip to the end of this code block (the ending } for the switch or the loop)
* Using a break statement inside an if-else statement, we can rewrite the previous while loop so that the variable success is not needed:

int sum = 0, userNum = 0;  
while(userNum >= 0)  
{  
 sum += userNum;  
 Console.WriteLine("Enter a positive number to add it. "  
 + "Enter anything else to stop.");  
 if(!int.TryParse(Console.ReadLine(), out userNum))  
 break;  
}  
Console.WriteLine($"The sum of your numbers is {sum}");

* Inside the body of the loop, the return value of TryParse can be used directly in an if statement instead of assigning it to the success variable
* If TryParse fails, the break statement will end the loop, so there is no need to add success to the while condition
* We can also use the break statement with a for loop, if there are some cases where the loop should end before the counter reaches its last value
* For example, imagine that our program is given an int array that a user *partially* filled with numbers, and we need to find their product. The “unused” entries at the end of the array are all 0 (the default value of int), so the for loop needs to stop before the end of the array if it encounters a 0. A break statement can accomplish this:

int product = 1;  
for(int i = 0; i < myArray.Length; i++)  
{  
 if(myArray[i] == 0)  
 break;  
 product \*= myArray[i];  
}

* If myArray[i] is 0, the loop stops before it can multiply the product by 0
* If all of the array entries are nonzero, though, the loop continues until i is equal to myArray.Length
* Note that in this example, we access each array element once and do not modify them, so we could also write it with a foreach loop:

int product = 1;  
foreach(int number in myArray)  
{  
 if(number == 0)  
 break;  
 product \*= number;  
}

# The Conditional Operator

* There are many situations where we need to assign a variable to a different value depending on the result of a condition
* For example, the if-else-if and switch statements in the previous section were used to decide which value to assign to the variable monthName
* A simpler example: Imagine your program needs to tell the user whether a number is even or odd. You need to initialize a string variable to either “Even” or “Odd” depending on whether myInt % 2 is equal to 0. We could write an if statement to do this:

string output;  
if(myInt % 2 == 0)  
{  
 output = "Even";  
}  
else  
{  
 output = "Odd";  
}

## Assignment with the conditional operator

* If the only thing an if statement does is assign a value to a variable, there is a much shorter way to write it
* The **conditional operator** ?: tests a condition, and then outputs one of two values based on the result
* Continuing the “even or odd” example, the conditional operator is used like this:

string output = (myInt % 2 == 0) ? "Even" : "Odd";

When this line of code is executed:

* The condition (myInt % 2 == 0) is evaluated, and the result is either true or false
* If the condition is true, the conditional operator returns (outputs) the value "Even" (the left side of the :)
* If the condition is false, the operator returns the value "Odd" (the right side of the :)
* This value, either “Even” or “Odd”, is used in the initialization statement for string output
* Thus, output gets assigned the value "Even" if (myInt % 2 == 0) is true, or "Odd" if (myInt % 2 == 0) is false
* In general, the syntax for the conditional operator is:

condition ? true\_expression : false\_expression;

* The “condition” can be any expression that produces a bool when evaluated, just like in an if statement
* true\_expression and false\_expression can be variables, values, or more complex expressions, but they must both produce the same *type* of data when evaluated
* For example, if true\_expression is myInt \* 1.5, then false\_expression must also produce a double
* When the conditional operator is evaluated, it returns either the value of true\_expression or the value of false\_expression (depending on the condition) and this value can then be used in other operations such as assignment

## Conditional operator examples

* The true\_expression and false\_expression can both be mathematical expressions, and only one of them will get computed. For example:

int answer = (myInt % 2 == 0) ? myInt / 2 : myInt + 1;

If myInt is even, the computer will evaluate myInt / 2 and assign the result to answer. If it is odd, the computer will evaluate myInt + 1 and assign the result to answer.

* Conditional operators can be used with user input to quickly provide a “default value” if the user’s input is invalid. For example, we can write a program that asks the user their height, but uses a default value of 0 if the user enters a negative height:

Console.WriteLine("What is your height in meters?");  
double userHeight = double.Parse(Console.ReadLine());  
double height = (userHeight >= 0.0) ? userHeight : 0.0;

* The condition can be a Boolean variable by itself, just like in an if statement. This allows you to write code that looks kind of like English, due to the question mark in the conditional operator. For example,

bool isAdult = age >= 18;  
decimal price = isAdult ? 5.0m : 2.5m;  
string closingTime = isAdult ? "10:00 pm" : "8:00 pm";

# Recursion

The code for this lecture is available [in this archive](https:/princomp.github.io/code/projects/RecursionHelloWorld.zip) (first parts) and [this one](https:/princomp.github.io/code/projects/ListDirectoriesFileRecursively.zip) (listing files and folders recursively).

## Introduction

Recursion is a central notion in programming, simple to state but difficult to master: a method is *recursive* if it calls itself. This concept is related to the idea of repetition, or looping, of program parts, and come with the same danger of not terminating. Below, we present some simple recursive programs: while some could be written without recursion, some would be very hard, if possible at all, to write without using recursion.

## First Examples

Consider the following:

static void displayAll(int n)  
 {  
 if (n > 0)  
 {  
 Console.Write($"{n} ");  
 displayAll(n - 1);  
 }  
 }

If we call displayAll(3);, then the following will happen:

1. displayAll(3) will test that 3>0,
2. displayAll(3) will display “3 ”,
3. displayAll(3) will call displayAll(2),
   1. displayAll(2) will test that 2>0,
   2. displayAll(2) will display “2 ”,
   3. displayAll(2) will call displayAll(1),
      1. displayAll(1) will test that 1>0,
      2. displayAll(1) will display “1 ”,
      3. displayAll(1) will call displayAll(0),
         1. displayAll(0) will test that 0>0,
         2. displayAll(0) will terminate.
      4. displayAll(1) will terminate.
   4. displayAll(2) will terminate.
4. displayAll(3) will terminate.

Hence, displayAll calls itself with a smaller number, unless that number is 0, in which case it simply terminates. In our example, it would display “3 2 1 ”.

*When* the function calls itself matters a lot. Indeed, consider displayRAll, which calls itself *before* executing the Console.WriteLine instruction:

static void displayRAll(int n)  
 {  
 if (n > 0)  
 {  
 displayRAll(n - 1);  
 Console.Write($"{n} ");  
 }  
 }

If we call displayRall(3);, then the following will happen:

1. displayRall(3) will test that 3>0,
2. displayRall(3) will call displayRall(2),
   1. displayRall(2) will test that 2>0,
   2. displayRall(2) will call displayRall(1),
      1. displayRall(1) will test that 1>0,
      2. displayRall(1) will call displayRall(0),
         1. displayRall(0) will test that 0>0,
         2. displayRall(0) will terminate.
      3. displayRall(1) will display “1 ”,
      4. displayRall(1) will terminate.
   3. displayRall(2) will display “2 ”,
   4. displayRall(2) will terminate.
3. displayRall(3) will display “3 ”,
4. displayRall(3) will terminate.

In this example, “1 2 3 ” would be displayed: the order is reversed with respect to displayAll!

| ❗ Caution |
| --- |
| Recursion can be very powerful and can very easily make your program crash or misbehave. To see it for yourself, *after saving all important documents*, replace - with + in the previous examples and run the programs again. |

displayAll is an example of *tail recursion*: the recursive call is the **last** statement in the method. displayRAll is an example of *head recursion*: the recursive call is the **first** statement in the method. They are furthormore both examples of *linear recursion*, as they call themselves only once.

## Recursive Methods Returning a Value

Recursive methods can also return a value, used by previous calls to compute some other value.

### Multiplication

For example, consider that multiplication can be defined by addition: indeed, is where is summed times. Stated differently (read: recursively), is . We can implement such a program easily:

static int mult(int x, int y)  
 {  
 if (x == 0)  
 {  
 return 0;  
 }  
 else if (x == 1)  
 {  
 return y;  
 }  
 else  
 {  
 return y + mult(x - 1, y);  
 }  
 }

For example, mult(2, 10) tests that 2 is neither 0 nor 1, and adds 10 with the result of mult(1, 10), which is 10 since the first argument is 1.

Observe that mult(10000000, 0) would call mult 10000001 times and add 0 to itself 10000001 times: this algorithm is not very efficient!

### Factorial

The factorial of is . This function can easily be implemented using recursion:

static int factorial(int n)  
 {  
 if (n == 0)  
 return 1;  
 else  
 return (factorial(n - 1) \* n);  
 }

Note that this code actually compute e.g., (with one superfluous ): can you see why?

## Listing Files and Directories, Recursively

While multiplication and factorial can be implemented without recursion, some structures makes it natural, or even required, to use recursion. Going through folders and files is an example of such situation.

﻿using System;  
using System.IO;  
  
class Program  
{  
 static void Main()  
 {  
 // We first locate where we currently are.  
 DirectoryInfo currentDir = new DirectoryInfo(  
 Directory.GetCurrentDirectory()  
 );  
 Console.WriteLine("Starting from " + currentDir + ".");  
 int count = 5;  
 // We go up 5 folders or until we reach the  
 // root folder, whichever comes first.  
 while (currentDir.Parent != null && count > 0)  
 {  
 currentDir = currentDir.Parent;  
 count--;  
 Console.WriteLine("Going up to " + currentDir + ".");  
 }  
 Console.WriteLine(  
 "Now listing files and folders from here:"  
 );  
 ListDir(currentDir.ToString());  
 }  
  
 // Code in part inspired from  
 // https://stackoverflow.com/a/929277  
 static void ListDir(string sourceDir)  
 {  
 try  
 {  
 Console.WriteLine(sourceDir);  
  
 foreach (string file in Directory.GetFiles(sourceDir))  
 Console.WriteLine(file);  
  
 foreach (  
 string directory in Directory.GetDirectories(  
 sourceDir  
 )  
 )  
 ListDir(directory);  
 }  
 catch (Exception e)  
 {  
 Console.WriteLine(e.Message);  
 }  
 }  
}

Note that our previous examples were calling themselves only once per method call, but that ListDir calls itself as many times as there are folders in the folder currently examined.

# More on Recursion

The code for this lecture is available [in this archive](https:/princomp.github.io/code/projects/AdvancedRecursion.zip).

## Re-Introduction

We previously defined recursion as follows:

a method is *recursive* if it calls itself.

Applied very strictly, the simplest (and most likely shortest) recursive method is the following:

// Warning: dangerous function!  
 void R()  
 {  
 R();  
 }

It is a method (R) that simply … calls itself. Even if this method does not “do” anything, calling it will most likely make your program crash, since R will keep calling itself forever: this is actually an example of an infinite loop, and the basics of the [“fork bomb” attack](https://en.wikipedia.org/wiki/Fork_bomb)[[13]](#footnote-13).

A better definition of recursion would include something about the method eventually terminating, like the following:

void CountDown(int n)  
 {  
 if (n == 0)  
 {  
 Console.WriteLine($"{n}: Blast off!");  
 }  
 else  
 {  
 Console.Write($"{n}…");  
 CountDown(n - 1);  
 }  
 }

In that case, if we call e.g., CountDown(10), then would be displayed:

10…9…8…7…6…5…4…3…2…1…0: Blast off!

But note that this method is not *always* terminating: indeed, calling CountDown(-1) actually loops forever, since removing 1 to -1 repetitively will never make it reach 0 (if we forget about overflows for an instant).

A possible way to patch this would be to have two additional method: one to count “up” to 0, and one that decides which method to call:

void CountUp(int n)  
 {  
 if (n == 0)  
 {  
 Console.WriteLine($"{n}: Blast off!");  
 }  
 else  
 {  
 Console.Write($"{n}…");  
 CountUp(n + 1); // <- Only change.  
 }  
 }  
 void Count(int n)  
 {  
 if (n < 0)  
 CountUp(n);  
 else  
 CountDown(n);  
 }  
 Count(10);  
 Count(-10);

As we can see, Count itself is *not* recursive, but it calls a recursive method.

Finally, methods can be *mutually recursive*: a method MyTurn can call a YourTurn method that itself calls MyTurn. While neither method are recursive, they create a recursive situation, as exemplified below:

void MyTurn(int n)  
 {  
 if (n < 0)  
 {  
 Console.WriteLine("The Game is over.");  
 }  
 else  
 {  
 Console.WriteLine("It's my turn");  
 n--;  
 if (n < 0)  
 {  
 Console.WriteLine("The Game is over.");  
 }  
 else  
 {  
 YourTurn(n);  
 }  
 }  
 }  
 void YourTurn(int n)  
 {  
 Console.WriteLine("It's your turn.");  
 MyTurn(n);  
 }

Note that determining how many time both methods will be executed may not be easy: in our example, if MyTurn(4) is called, can you determine what will be displayed?

## Arrays and Recursion

Any structure over which we can iterate can be treated using recursion, and arrays are no exception. In the following, we will re-implement two simple methods using recursion: one to decide if an array is sorted, and one that implements binary search.

### Sorted Array Using Recursion

Given an array and a current index, to determine if the array *is sorted*, one can:

* Make sure that the array to the left of the current index *is sorted*,
* Make sure that the value at the current index is less than the value at the next index,
* Make sure that the array to the right of the current index *is sorted*.

Note that our definition above is recursive: *being sorted* is defined using *being sorted*.

Assuming the array is sorted up to currentIndex, the following will return true if the rest of the array is sorted, false otherwise:

bool SortedH(int[] aP, int currentIndex)  
 {  
 if (aP.Length == currentIndex + 1)  
 return true;  
 else if (aP[currentIndex] > aP[currentIndex + 1])  
 return false;  
 else  
 return SortedH(aP, currentIndex + 1);  
 }

The first test check if we are done (in which case the array *is* sorted), the second compare the value at the current index with the one that follows, and the last one kicks in the reduction by stipulating that if the other two tests failed, then the array is sorted if the rest of the array is.

Compared to our informal above, we are missing the “making sure the left of the current index is sorted” bit, *unless* we start with current index … 0! Putting it all together, we can define Sorted calling the recursive SortedH method with the right arguments (and after performing some checks):

bool Sorted(int[] aP)  
 {  
 if (aP == null)  
 return false;  
 else  
 return SortedH(aP, 0);  
 }

### Binary Search Using Recursion

We can perform [binary search](https:/princomp.github.io/lectures/collections/search#binary-search) using recursion:

bool BinFindH(int[] aP, int start, int end, int target)  
 {  
 int mid = (start + end) / 2;  
 if (start > end)  
 {  
 return false;  
 }  
 else  
 {  
 if (target == aP[mid])  
 {  
 return true;  
 }  
 else if (target > aP[mid])  
 {  
 return BinFindH(aP, mid + 1, end, target);  
 }  
 else  
 {  
 return BinFindH(aP, start, mid - 1, target);  
 }  
 }  
 }  
 // Binary search  
 bool BinFind(int[] aP, int target)  
 {  
 return BinFindH(aP, 0, aP.Length - 1, target);  
 }

## Lists and Recursion

Lists are also naturally manipulated by recursive methods. We show, as an example, two ways of defining a method that construct a string describing a .NET list.

string DisplayH(  
 string retString,  
 List<string> listP,  
 int indexP  
 )  
 {  
 if (listP.Count == indexP + 1)  
 {  
 return retString + listP[indexP] + ".\n";  
 }  
 else  
 {  
 retString += listP[indexP] + " -> ";  
 return DisplayH(retString, listP, indexP + 1);  
 }  
 }  
  
 string Display(List<string> ListP)  
 {  
 string retString = "";  
 return DisplayH(retString, ListP, 0);  
 }

Note that the DisplayH method is a bit cumbersome, as it must carry around

1. The whole list (listP),
2. The string that is being constructed (retString),
3. An index (indexP).

An alternative way of writing such a method is to

1. shorten the list as we go (using RemoveAt),
2. and to use a *reference* to the string,

as follows:

void DisplayRef(ref string descP, List<string> listP)  
 {  
 if (listP == null || listP.Count == 0)  
 {  
 descP += ".\n";  
 }  
 else if (listP.Count == 1)  
 {  
 descP += listP[0] + ".\n";  
 }  
 else  
 {  
 descP += listP[0] + " -> ";  
 listP.RemoveAt(0);  
 DisplayRef(ref descP, listP);  
 }  
 }

**But note that the list is *actually* shortened** by the RemoveAt instruction: if we additionally have to leave the original string unmodified, then a copy of the list must be created, using e.g.

List<string> listCopy = new List<string>(  
 operatingSystems  
 );

# Introduction

Arrays are structures that allow you to store multiple values in memory using a single name and indexes. Internally, an array contains a fixed number of variables (called *elements*) of a particular type[[14]](#footnote-14). The elements in an array are always stored in a contiguous block of memory, providing fast and efficient access.

An array can be:

* Single-Dimensional,
* Multidimensional.

Multidimensional arrays can be

* Jagged,
* Rectangular.

Arrays are useful, for instance,

* When you want to store a collection of related values,
* When you do not know in advance how many variables will be needed,
* When you need a large number of variables (say, 10) of the same type,
* When you want to represent matrices (as you can use an array of arrays to represent 2-dimensional objects).

# Single-Dimensional Arrays

## Introduction

You can define a single-dimensional array as follow:

<type>[] arrayName;

where

* <type> can be any data-type and specifies the data-type of the array elements.
* arrayName is an identifier that you will use to access and modify the array elements.

Before using an array, you must specify the number of elements in the array as follows:

arrayName = new <type>[<number of elements>];

where <type> is a type as before, and <number of elements>, called the *size declarator*, is a strictly positive integer which will correspond to the size of the array.

* An element of a single-dimensional array can be accessed and modified by using the name of the array and the index of the element as follows:

// Assigns <value> to the <index> element of the array arrayName.  
arrayName[<index>] = <value>;   
  
// Display the <index> element of the array arrayName.  
Console.WriteLine(arrayName[<index>]);

The index of the first element in an array is always *zero*; the index of the second element is one, and the index of the last element is the size of the array minus one. As a consequence, if you specify an index greater or equal to the number of elements, a run-time error will happen.

Indexing starting from 0 may seem surprising and counter-intuitive, but this is a largely respected convention across programing languages and computer scientists. Some insights on the reasons behind this (collective) choice can be found [in this answer on Computer Science Educators](https://cseducators.stackexchange.com/a/5026).

## Example

In the following example, we define an array named myArray with three elements of type integer, and assign 10 to the first element, 20 to the second element, and 30 to the last element.

int[] myArray;  
myArray = new int[3]; // 3 is the size declarator  
// We can now store 3 ints in this array,  
// at index 0, 1 and 2  
  
myArray[0] = 10; // 0 is the subscript, or index  
myArray[1] = 20;  
myArray[2] = 30;

If we were to try to store a fourth value in our array, at index 3, using e.g.

myArray[3] = 40;

our program would compile just fine, which may seems surprising. However, when executing this program, *array bounds checking* would be performed and detect that there is a mismatch between the size of the array and the index we are trying to use, resulting in a quite explicit error message:

Unhandled Exception: System.IndexOutOfRangeException: Index was outside the bounds of the array at Program.Main()

## Abridged Syntaxes

If you know the number of elements when you are defining an array, you can combine declaration and assignment on one line as follows:

<type>[] arrayName = new <type>[<number of elements>];

So, we can combine the first two lines of the previous example and write:

int[] myArray = new int[3];

We can even initialize *and* give values on one line:

int[] myArray = new int[3] { 10, 20, 30 };

And that statement can be rewritten as any of the following:

int[] myArray = new int[] { 10, 20, 30 };  
int[] myArray = new[] { 10, 20, 30 };  
int[] myArray = { 10, 20, 30 };

But, we should be careful, the following would cause an error:

int[] myArray = new int[5];  
myArray = { 1, 2 ,3, 4, 5}; // ERROR

If we use the shorter notation, we *have to* give the values at initialization, we cannot re-use this notation once the array has been created.

Other datatypes, and even objects, can be stored in arrays in a perfectly similar way:

string[] myArray = { "Bob", "Mom", "Train", "Console" };  
  
// Assume there is a class called Rectangle.  
Rectangle[] arrayOfRectangle = new Rectangle[5];

# Simple Loops and Length

## Custom Size and Loops

One of the benefits of arrays is that they allow you to specify the number of their elements at run-time: the size declarator can be a variable, not just an integer literal. Hence, depending on run-time conditions such as user input, we can have enough space to store and process any number of values.

In order to access the elements of whose size is not known until run-time, we will need to use a loop. If the size of myArray comes from user input, it wouldn’t be safe to try to access a specific element like myArray[5], because we cannot guarantee that the array will have at least 6 elements. Instead, we can write a loop that uses a counter variable to access the array, and use the loop condition to ensure that the variable does not exceed the size of the array.

### Example

In the following example, we get the number of elements at run-time from the user, create an array with the appropriate size, and fill the array.

Console.WriteLine("What is the size of the array that you want?");  
int size = int.Parse(Console.ReadLine());  
int[] customArray = new int[size];  
  
int counter = 0;  
while (counter < size)  
{  
 Console.WriteLine($"Enter the {counter + 1}th value");  
 customArray[counter] = int.Parse(Console.ReadLine());  
 counter++;  
}

Observe that:

* If the user enters a negative value or a string that does not correspond to an integer for the size value, our program will crash: we are not performing any user-input validation here, to keep our example compact.
* The loop condition is counter < size because we do *not* want the loop to execute when counter is equal to size. The last valid index in customArray is size - 1.
* We are asking for the {counter +1}th value because we prefer not to confuse the user by asking for the “0th” value. Note that a more sophisticated program would replace “th” with “st”, “nd” and “rd” for the first three values.

### The Length Property

Every single-dimensional array has a property called Length that returns the number of the elements in the array (or size of the array).

To process an array whose size is not fixed at compile-time, we can use this property to find out the number of elements in the array.

### Example

int counter2 = 0;  
while (counter2 < customArray.Length)  
{  
 Console.WriteLine($"{counter2}: {customArray[counter2]}.");  
 counter2++;  
}

Observe that this code does not need the variable size.

Note: You *cannot* use the length property to change the size of the array, that is, entering

int[] test = new int[10];  
test.Length = 9;

would return, at compile time,

Compilation error (line 8, col 3): Property or indexer 'System.Array.Length' cannot be assigned to --it is read only.

When a field is marked as ‘read only,’ it means the attribute can only be initialized during the declaration or in the constructor of a class. We receive this error because the array attribute, ‘Length,’ can not be changed once the array is already declared. Resizing arrays will be discussed in the section: [Changing the Size](#changing-the-size).

## For Loops With Arrays

* Previously, we learned that you can iterate over the elements of an array using a while loop. We can also process arrays using for loops, and in many cases they are more concise than the equivalent while loop.
* For example, consider this code that finds the average of all the elements in an array:

int[] homeworkGrades = {89, 72, 88, 80, 91};  
int counter = 0;  
int sum = 0;  
while(counter < 5)  
{  
 sum += homeworkGrades[counter];  
 counter++  
}  
double average = sum / 5.0;

* This can also be written with a for loop:

int sum = 0;  
for(int i = 0; i < 5; i++)  
{  
 sum += homeworkGrades[i];  
}  
double average = sum / 5.0;

* In a for loop that iterates over an array, the counter variable is also used as the array index
* Since we did not need to use the counter variable outside the body of the loop, we can declare it in the loop header and limit its scope to the loop’s body
* Using a for loop to access array elements makes it easy to process “the whole array” when the size of the array is user-provided:

Console.WriteLine("How many grades are there?");  
int numGrades = int.Parse(Console.ReadLine());  
int[] homeworkGrades = new int[numGrades];  
for(int i = 0; i < numGrades; i++)  
{  
 Console.WriteLine($"Enter grade for homework {i+1}");  
 homeworkGrades[i] = int.Parse(Console.ReadLine());  
}

* You can use the Length property of an array to write a loop condition, even if you did not store the size of the array in a variable. For example, this code does not need the variable numGrades:

int sum = 0;  
for(int i = 0; i < homeworkGrades.Length; i++)  
{  
 sum += homeworkGrades[i];  
}  
double average = (double) sum / homeworkGrades.Length;

* In general, as long as the loop condition is in the format i < <arrayName>.Length (or, equivalently, i <= <arrayName>.Length - 1), the loop will access each element of the array.

# Default Values and Resizing

When created, arrays have a fixed size and are populated with some *default values*. We discuss here what those default values are, how an array can be resized, and how we can avoid resizing an array.

## Default Values

If we initialize an array but do not assign any values to its elements, each element will get the default value for that element’s data type. (These are the same default values that are assigned to instance variables if we do not write a constructor, as we learned in “More Advanced Object Concepts”). In the following example, each element of myArray gets initialized to 0, the default value for int:

int[] myArray = new int[5];  
Console.WriteLine(myArray[2]); // Displays "0"  
myArray[1]++;  
Console.WriteLine(myArray[1]); // Displays "1"

However, remember that the default value for any *object* data type is null, which is an object that does not exist. Attempting to call a method on a null object will cause a run-time error of the type System.NullReferenceException;

Rectangle[] shapes = new Rectangle[3];  
shapes[0].SetLength(5); // ERROR

Before we can use an array element that should contain an object, we must instantiate an object and assign it to the array element. For our array of Rectangle objects, we could either write code like this:

Rectangle[] shapes = new Rectangle[3];  
shapes[0] = new Rectangle();  
shapes[1] = new Rectangle();  
shapes[2] = new Rectangle();

or use the abridged initialization syntax as follows:

Rectangle[] shapes = {new Rectangle(), new Rectangle(), new Rectangle()};

## Changing the Size

There is a class named Array that can be used to resize an array. Upon expanding an array, the additional indices will be filled with the default value of the corresponding type. Shrinking an array will cause the data in the removed indices (those beyond the new length) to be lost.

### Example

Array.Resize(ref myArray, 4); //myArray[3] now contains 0  
myArray[3] = 40;  
Array.Resize(ref myArray, 2);

In the above example, all data starting at index 2 is lost.

## Partially Filled Arrays

To avoid resizing an array, it also possible to declare it *larger than it needs to be*, and then to manipulate an accompanying integer variable that holds the number of elements that are actually stored in the array. The [solution to the todo list project](https:/princomp.github.io/projects/todolist/solution) illustrates this behavior in detail, the general idea is that you want to let the user store some elements without having to say ahead of time how many, and without having to resize the array constantly. The drawback is that the Length property becomes less useful, and that you have to manipulate a custom “accounting” variable to keep track of the actual number of elements manipulated.

using System;  
  
public class Program  
{  
 public static void Main(string[] args)  
 {  
 // We decide that the maximum number of input is 10.  
 const int MAXSIZE = 10;  
  
 int[] inputs = new int[MAXSIZE];  
  
 // The following variable will contain the number of input actually given.  
 int numberOfInputs = 0;  
  
 // The following variable will hold the user input.  
 string uInput;  
  
 do  
 {  
 Console.WriteLine(  
 "What is your input #"  
 + (numberOfInputs + 1)  
 + "? Enter \"done\" when you are done."  
 );  
 uInput = Console.ReadLine();  
 if (uInput != "done")  
 {  
 inputs[numberOfInputs] = int.Parse(uInput);  
 numberOfInputs++; // We increment the number of items in the list.  
 }  
 if (numberOfInputs == MAXSIZE)  
 {  
 Console.WriteLine(  
 "You have reached the maximum number of inputs."  
 );  
 }  
 } while (uInput != "done" && numberOfInputs < MAXSIZE);  
 /\*  
 \* When the user enters "done", or if the user reached the maximum number of inputs, we exit this loop.  
 \*/  
 }  
}

# Searching in Arrays

We now discuss how we can search for values in an array.

## Finding the Maximum Value

To find the greatest value in an array of integer, one needs a comparison point, a variable holding “the greatest value *so far*”. Once this value is set, then one “just” have to inspect each value in the array, and to update “the greatest value *so far*” if the value currently inspected is greater, and then to move on to the next value. Once we reach the end of the array, we know that “the greatest value *so far*” is actually the greatest value (period) in the array.

The problem is to find the starting point: one cannot assume that “the greatest value *so far*” is (what if the array contains only negative values?), so the best strategy is simply to assume that “the greatest value *so far*” is the first one in the array (after all, it *is* the greatest value we have seen *so far*).

Using foreach, we have for example the following:

int[] arrayExample = { 1, 8, -12, 9, 10, 1, 30, 1, 32, 3 };  
  
int maxSoFar = arrayExample[0];  
foreach (int i in arrayExample)  
 if (i > maxSoFar) maxSoFar = i;  
  
Console.WriteLine("The greatest value is "  
 + maxSoFar + ".");

## Finding a Particular Value

Suppose we want to set a particular Boolean variable to true if a particular value target is present in an arrayy arrayExample. The simplest way to perform such a search is to

1. Set the Boolean variable to false,
2. Inspect the values in arrayExample one by one, comparing them to target, and setting the Boolean variable to true if they are identical.

int[] arrayExample = { 1, 8, -12, 9, 10, 1, 30, 1, 32, 3 };  
  
bool foundTarget = false;  
int target = 8;  
  
for (int i = 0; i < arrayExample.Length; i++)  
{  
 if (arrayExample[i] == target) foundTarget = true;  
}  
Console.WriteLine(target + " is in the array: " + foundTarget + ".");

Note that in the particular example above, we could have stopped exploring the array after the second index, since the target value was found. A slightly different logic would allow to exit prematurely the loop when the target value is found:

int[] arrayExample = { 1, 8, -12, 9, 10, 1, 30, 1, 32, 3 };  
  
bool foundYet = false;  
int target = 30;  
int index = 0;  
  
do  
{  
 if (arrayExample[index] == target) foundYet = true;  
 index++;  
}  
while (index < arrayExample.Length && !foundYet);  
Console.WriteLine(target + " is in the array: " + foundYet +   
"\nNumber of elements inspected: " + (index) +".");

This code would display:

30 is in the array: True  
Number of elements inspected: 7.

Both codes are examples of *linear* (or *sequential*) *search*: the array is parsed one element after the other, and potentially all elements are inspected.

## Finding a Particular Value in a Sorted Array

If the array is *sorted* (that is, the value at index is less than the value at index ), then the search for a particular value can be sped up by using *binary search*.

### Sorted Arrays

A way of making sure that an array is sorted is given below. Note that, as above when trying to find the maximum value, we decide that the array is “sorted so far” unless proven otherwise, in which case we exit prematurely the loop. Note also that the condition contains index + 1 < arrayExample.Length: we need to make sure that “the next value” actually exists before comparing it with the current value.

int[] arrayExample = { 1, 10, 12, -1};  
bool sortedSoFar = true;  
int index = 0;  
  
while (index + 1 < arrayExample.Length && sortedSoFar)  
{  
 if (arrayExample[index] > arrayExample[index+1]) sortedSoFar = false;  
 index++;  
}  
Console.WriteLine("The array is sorted: " + sortedSoFar +".");

### Binary Search

#### Introduction

*Binary* (*half-interval* or *logarithmic*) *search* leverages the fact that the array is sorted to speed up the search for a particular value. It goes as follows:

The algorithm compares the target value to the middle element of the array.

1. If they are equal, we are done.
2. If they are not equal, then there are two cases:
   1. If the middle element is greater than the target, then the algorithm restarts, but looking for the value only in the left half of the array,
   2. If the middle element is less than the target, then the algorithm restarts, but looking for the value only in the right half of the array.
3. If the search ends with the remaining half being empty, the target is not in the array.

#### First Example

An example of implementation (and of execution) is as follows:

int[] arrayExample = { 1, 10, 12, 129, 190, 220, 230, 310, 320, 340, 400, 460};  
bool foundSoFar = false;  
  
int target = 340;  
  
int start = 0;  
int end = arrayExample.Length - 1;  
int mid;  
while (start <= end && !foundSoFar)  
{  
 mid = (start + end) / 2;  
 /\*  
 \* This is integer division: if start + end is odd,  
 \* then it will be truncated. In our example,   
 \* (0 + 11) / 2 gives 5.  
 \*/  
 Console.WriteLine("The middle index is " + mid + ".");  
 if (target == arrayExample[mid])  
 {  
 foundSoFar = true;  
 }  
 else if (target > arrayExample[mid])  
 {  
 start = mid + 1;  
 Console.WriteLine("I keep looking right.");  
 }  
 else  
 {  
 end = mid - 1;  
 Console.WriteLine("I keep looking left.");  
 }  
}  
Console.WriteLine("Found the value: " + foundSoFar +".");

This code would display:

The middle index is 5.  
I keep looking right.  
The middle index is 8.  
I keep looking right.  
The middle index is 10.  
I keep looking left.  
The middle index is 9.  
Found the value: True.

#### Second Example

Remembering that characters are such that 'A' is less than 'a', and 'a' is less than 'b', we can run a binary search on a sorted array of characters. The code below is the same algorithm as above, only the information logged changes:

char[] arrayExample = { 'A', 'B', 'D', 'Z', 'a', 'b', 'd' };  
char target = 'D';  
bool foundSoFar = false;  
int start = 0;  
int end = arrayExample.Length - 1;  
int mid;  
while (start <= end && !foundSoFar)  
{  
 Console.WriteLine("Range: " + start + " -- " + end);  
 mid = (start + end) / 2;  
 Console.WriteLine("Mid: " + mid);  
 if (target == arrayExample[mid])  
 {  
 foundSoFar = true;  
 }  
 else if (target > arrayExample[mid])  
 {  
 start = mid + 1;  
 }  
 else  
 {  
 end = mid - 1;  
 }  
}  
Console.WriteLine("Found the value: " + foundSoFar + ".");

This will display:

Range: 0 -- 6  
Mid: 3  
Range: 0 -- 2  
Mid: 1  
Range: 2 -- 2  
Mid: 2  
Found the value: True

Observe that if we were to replace start <= end with start < end then the algorithm would not have correctly terminated in the example above.

# Arrays of Objects

An array can contain more than simple datatypes: it can contain objects. It can be objects from a custom class, or even … arrays, which are themselves objects!

## Array of Objects From a Custom Class

In the following example, we will ask the user how many Item objects (the details of the implementation do not matter, but can be [inspired by this example](https:/princomp.github.io/lectures/flow/control_flow_and_classes#setters-with-input-validation)) they want to create, then fill an array with Item objects initialized from user input:

Console.WriteLine("How many items would you like to stock?");  
Item[] items = new Item[int.Parse(Console.ReadLine())];  
int i = 0;  
while(i < items.Length)  
{  
 Console.WriteLine($"Enter description of item {i+1}:");  
 string description = Console.ReadLine();  
 Console.WriteLine($"Enter price of item {i+1}:");  
 decimal price = decimal.Parse(Console.ReadLine());  
 items[i] = new Item(description, price);  
 i++;  
}

Observe that, since we do not perform any user-input validation, we can simply use the result of int.Parse() as the size declarator for the items array - no size variable is needed at all.

We can also use while loops to search through arrays for a particular value. For example, this code will find and display the lowest-priced item in the array items, which was initialized by user input:

Item lowestItem = items[0];  
int i = 1;  
while(i < items.Length)  
{  
 if(items[i].GetPrice() < lowestItem.GetPrice())  
 {  
 lowestItem = items[i];  
 }  
 i++;  
}  
Console.WriteLine($"The lowest-priced item is {lowestItem}");

Note that the lowestItem variable needs to be initialized to refer to an Item object before we can call the GetPrice() method on it; we cannot call GetPrice() if lowestItem is null. We could try to create an Item object with the “highest possible” price, but a simpler approach is to initialize lowestItem with items[0]. As long as the array has at least one element, 0 is a valid index, and the first item in the array can be our first “guess” at the lowest-priced item.

## Arrays of Arrays

An array of arrays is called a multi-dimensional array. A multi-dimensional array can be rectangular (it then represents an -dimensional block of memory) or jagged (in that case, it is an array of arrays).

### Rectangular Multi-Dimensional Array

Also called -dimensional arrays, their syntax is very close to that of -dimensional arrays:

int[,] matrix = new int[2, 3];

where 2 is the number of rows, and 3 is the number of columns. They can be accessed with matrix.GetLength(0) and matrix.GetLength(1) respectively.

Assignment is as for -dimensional arrays, starting at :

matrix[0, 0] = 1;  
matrix[0, 1] = 2;  
matrix[0, 2] = 3;  
matrix[1, 0] = 4;  
matrix[1, 1] = 5;  
matrix[1, 2] = 6;

This will produce a matrix as follows:

|  | 0th col. | 1st col. | 2nd col. |
| --- | --- | --- | --- |
| 0th row | 1 | 2 | 3 |
| 1st row | 4 | 5 | 6 |

We could also have used a shortened notation to declare this -dimensional array, as follows:

int[,] matrix = new int[,]  
{  
 {1,2,3},  
 {4,5,6}  
};

or even simply

int[,] matrix = {{1,2,3},{4,5,6}};

To display such an array, nested loops are needed:

for (int row = 0; row < matrix.GetLength(0); row++)  
{  
 for (int col = 0; col < matrix.GetLength(1); col++)  
 Console.Write(matrix[row, col] + " ");  
 Console.WriteLine();  
}

### Jagged Array

A jagged array is an array of arrays. The difference from rectangular arrays is that the arrays stored can be of varying sizes. The syntax of a jagged array is as follows:

int [][] jaggedArray = new int[3][];

Here, 3 is the number of rows, but the number of columns is not included: this is because the stored arrays are different sizes, so the number of columns will vary depending on the row.

The syntax is straightforward once understood that jagged arrays are *exactly* arrays of arrays:

int[][] jaggedArray = new int[3][];  
jaggedArray[0] = new int[3] { 1, 2, 3 };  
jaggedArray[1] = new int[2] { 4, 5 };  
jaggedArray[2] = new int[5] { 6, 7, 8, 9, 10 };  
  
for (int row = 0; row < jaggedArray.Length; row++)  
{  
 Console.Write("The row #" + row + " contain: ");  
 for (  
 int arrayCell = 0;  
 arrayCell < jaggedArray[row].Length;  
 arrayCell++  
 )  
 {  
 Console.Write(jaggedArray[row][arrayCell] + " ");  
 }  
 Console.WriteLine("");  
}

In this example, it should be clear that jaggedArray[row] is itself an array, and hence that we can use e.g., jaggedArray[row].Length or jaggedArray[row][arrayCell].

### Comparing Use Cases for Rectangular and Jagged Arrays

The main distinction between rectangular and jagged arrays is that the former is more consistent with its sizing–in other words, in a rectangular array, each array housed within it will be the same size in every row, by definition. In contrast, jagged arrays are not as consistent. This can be seen in the difference between how rectangular and jagged arrays are initialized. Recall that, when initializing a rectangular array, the number of rows and columns is required, but only the number of rows is required for a jagged array.

Therefore, when deciding which type of array to use in a given situation, you will want to base it off of whether you need an array that is predictable in its sizing. If you want to make a table where most or every cell will be filled, a rectangular array will make more sense, whereas a jagged array will be preferred when the number of entries per row could be highly variable or difficult to predict.

Rectangular arrays work well when creating a matrix (an array of numbers used in mathematics, especially in linear algebra) or a table/spreadsheet of data where the number of data points (and, therefore, the number of columns) is consistent in each row. Jagged arrays work well when the number of data points varies. A good example would be if you want to use an array to store the time it takes you to run a lap. If you run the same number of laps every single time you run, without fail, then a rectangular array may work here. However, the more likely scenario is that the number will vary. In this case, a jagged array is better: the array in each row will be whatever size it needs to be in order to accommodate all of the data.

# Manipulating Rectangular Arrays

We present below some simple algorithms to manipulate 2-dimensional (rectangular) arrays. The code for this lecture is available [in this archive](https:/princomp.github.io/code/projects/MagicSquare.zip).

## Summing the values row per row

The following code sum the values contained in a 2-dimensional array row per row, and display the result each time before moving on to the next row:

int[,] numbers =  
 {  
 { 1, 2, 3, 4 },  
 { 5, 6, 7, 8 },  
 };  
  
 int acc;  
 for (int row = 0; row < numbers.GetLength(0); row++)  
 {  
 acc = 0;  
 for (int col = 0; col < numbers.GetLength(1); col++)  
 {  
 acc += numbers[row, col];  
 }  
 Console.WriteLine(  
 "Total for row #" + row + " is " + acc + "."  
 );  
 }  
  
 //

This code can easily be adapted to compute the sums *column per column* if needed.

## Computing Magic Square

A [magic square](https://en.wikipedia.org/wiki/Magic_square) is a square matrix where the sums of the numbers in each row, each column, and both the diagonal and the anti-diagonal are the same.

The following is an example of a magic square:

int[,] arrayP1 =  
 {  
 { 4, 9, 2 },  
 { 3, 5, 7 },  
 { 8, 1, 6 },  
 };

as we have, diagonally,

and anti-diagonally,

and on the rows,

and finally on the columns

A method to return true if the 2d-matrix of int passed as an argument is a magic square is as follows:

static class MagicSquare  
{  
 public static bool isMagic(int[,] arrayP)  
 {  
 bool magicSoFar = true;  
 if (arrayP.GetLength(0) == arrayP.GetLength(1))  
 { // The array is a square.  
 int magicConstant = 0;  
 for (int i = 0; i < arrayP.GetLength(1); i++)  
 {  
 magicConstant += arrayP[i, i];  
 }  
 int testedValue = 0;  
 for (int i = 0; i < arrayP.GetLength(1); i++)  
 {  
 testedValue += arrayP[  
 i,  
 arrayP.GetLength(1) - i - 1  
 ];  
 }  
 if (testedValue == magicConstant)  
 { // The diagonal and anti-diagonal have the same sums.  
 // We test the rows.  
 for (int row = 0; row < arrayP.GetLength(0); row++)  
 {  
 testedValue = 0;  
 for (  
 int col = 0;  
 col < arrayP.GetLength(1);  
 col++  
 )  
 {  
 testedValue += arrayP[row, col];  
 }  
  
 if (testedValue != magicConstant)  
 {  
 magicSoFar = false;  
 }  
 }  
 // We test the columns.  
 for (int col = 0; col < arrayP.GetLength(1); col++)  
 {  
 testedValue = 0;  
 for (  
 int row = 0;  
 row < arrayP.GetLength(0);  
 row++  
 )  
 {  
 testedValue += arrayP[row, col];  
 }  
  
 if (testedValue != magicConstant)  
 {  
 magicSoFar = false;  
 }  
 }  
 }  
 else  
 { // The diagonal and anti-diagonal have different same sums.  
 magicSoFar = false;  
 }  
 }  
 else  
 { // The array is not a square.  
 magicSoFar = false;  
 }  
  
 return magicSoFar;  
 }  
}

# The List collections

## Introduction

The List class serves a similar purpose than arrays, but with a few notable differences:

* Lists do not need to have a number of elements fixed ahead of time,
* Lists automatically expand when elements are added,
* Lists automatically shrink when elements are removed,
* Lists require to have the using System.Collections.Generic; statement at the beginning of the file,
* Lists have many built-in methods.

The [complete description of the List class](https://learn.microsoft.com/en-us/dotnet/api/system.collections.generic.list-1?view=net-9.0) describes all the useful methods, we simply give a quick overview below.

## Syntax

### Creation

The syntax to create an empty list of string named nameList and a list of int named valueList containing 1, 2 and 3 is:

List<string> nameList = new List<string>();  
List<int> valueList = new List<int>() { 1, 2, 3 };

[*(Download this code)*](https:/princomp.github.io/code/projects/Lists.zip)

### Adding Elements

Adding an element to the list is done using the Add method, and counting the number of elements is done using the Count property:

Console.WriteLine(  
 "nameList has " + nameList.Count + " element."  
);  
nameList.Add("Bob");  
Console.WriteLine(  
 "nameList has " + nameList.Count + " element."  
);  
nameList.Add("Sandrine");  
Console.WriteLine(  
 "nameList has " + nameList.Count + " elements."  
);

Note that we did not need to resize the nameList manually: its size went from 0 to 1 after we added “Bob”, and from 1 to 2 after we added “Sandrine”.

### Accessing Elements

#### Using the indexer access operator

Accessing an element can be done using the same operator as with arrays (the [] operator, called [“indexer operator”](https://learn.microsoft.com/en-us/dotnet/csharp/language-reference/operators/member-access-operators#indexer-operator-)):

Console.WriteLine(nameList[0]);

will display “Bob”. Note that this syntax can be used to change the value of an element that already exist. For example,

nameList[0] = "Robert";

would replace the first value in the list (“Bob”) with “Robert”.

Note that while accessing or replacing an element using the [] operator inside a list is fine, *you cannot add new elements to the list using this syntax*. For example,

nameList[2] = "Sandrine";

would raise an exception since there is no third element to our list.

#### Using foreach

Another way of accessing the elements in a list is to use foreach loops:

foreach (string name in nameList)  
{  
 Console.WriteLine(name);  
}

### Removing Elements

An element can be removed from the list using the RemoveAt method. If nameList contains “Robert” and “Sandrine”, then after the following statement,

nameList.RemoveAt(0);

it would only contain “Sandrine” and its size would be 1. That is, the first element would be deleted and the list would shrink.

Another way of removing an element is to use the Remove method. Suppose we have the following list:

List<int> valueList2 = new List<int>()  
{  
 -1,  
 0,  
 1,  
 2,  
 3,  
 2,  
 5,  
};

then using

valueList2.Remove(1);

would remove “1” from the list, and the list would become -1, 0, 2, 3, 2, 5.

Observe that Remove returns a bool, so that for instance the following

if (valueList2.Remove(0))  
{  
 Console.WriteLine("0 was removed.");  
}

would not only remove 0 from the list, but also display “0 was removed”.

Finally, if the value is present multiple times in the list, then only its first occurrence is removed. For example, if the list is -1, 2, 3, 2, 5, then after executing

valueList2.Remove(2);

it would become -1, 3, 2, 5: observe that only the first occurrence of 2 was removed from the list.

# Custom Implementation of Lists

Our goal is to provide our own implementation of Lists, instead of using [the one provided by C#’s System.Collections.Generic namespace](https://learn.microsoft.com/en-us/dotnet/api/system.collections.generic.list-1?view=net-9.0). This will help in

* understanding how a simple *data structure* is implemented,
* understanding the differences between arrays and lists,
* developing simple algorithms traversing lists,
* visually representing how lists operate.

The “custom” implementation of list can be found [in this project](https:/princomp.github.io/code/projects/CList_Intro.zip), it is also extended [in this project](https:/princomp.github.io/code/projects/CList.zip) with many additional methods.

## Getting Started

Consider the following code:

﻿using System;  
  
public class CList<T>  
{  
 // A CList is … a Cell.  
 private Cell first;  
  
 // By default, a CList contains only an empty cell.  
 public CList()  
 {  
 first = null;  
 }  
 // A Cell is itself two things:  
 // - An element of data (of type T),  
 // - Another cell, containing the next element of data.  
 // We implement this using automatic properties:  
 private class Cell  
 {  
 public T Data { get; set; }  
 public Cell Next { get; set; }  
  
 public Cell(T dataP, Cell nextP)  
 {  
 Data = dataP;  
 Next = nextP;  
 }  
 }  
  
 // A method to add a cell at the beginning  
 // of the CList (to the left).  
 // We call it AddF for 'Add First'.  
 public void AddF(T dataP)  
 {  
 first = new Cell(dataP, first);  
 }  
 // The updated CList starts with a cell holding dataP and   
 // a Cell referencing the previous first cell.  
}

[*(Download this code)*](https:/princomp.github.io/code/projects/CList_Intro.zip)

The first two important observations are that

* Our CList class uses a [generic type parameter](https://princomp.github.io/lectures/oop/generic_types) (the <T> notation), so that we can create CLists containing bool, int, char, etc.,
* Our CList class contains itself a class, called Cell.

### Cell Class

Let us discuss the Cell class briefly. A Cell has two properties:

* Data, of type T, will hold the actual data: if we are creating a CList of ints, then each cell will hold an int in its Data property,
* Next, of type Cell, which contains a reference to the next Cell.

A Cell holding the Data of type int 12 and that has for Next value the Cell null will be represented as follows:

A diagram for a cell holding value 12 (text version, image version, svg version)

Intuitively, a Cell holds a piece of value (Data) and the “address” (more precisely, the reference) to the next Cell: “linking” Cells together is what gives *(singly) linked lists*, which is the [correct technical term](https://en.wikipedia.org/wiki/Linked_list#Singly_linked_list) for the type of list we are implementing (there are other ways of implementing lists).

### CList Class

### Creating an object

Now, let us zoom back and look at the CList class: a CList object has only one attribute, called first, which is a Cell. When a CList object is created, using for example the following:

CList<int> myList1 = new CList<int>();

then its first Cell is simply null:

public CList()  
 {  
 first = null;  
 }

We represent this situation as follows:

A diagram for a CList with only a null cell (text version, image version, svg version)

### Adding a Cell to a CList

To start adding elements to our CList myList1, we use the AddF method:

public void AddF(T dataP)  
 {  
 first = new Cell(dataP, first);  
 }

as follows:

myList1.AddF(12);

This method does the following:

1. It creates a Cell hoding dataP as its data, the “previous” first as its Next,
2. It updates first so that it refers this new Cell.

We would represent this situation as follows:

A diagram for a CList with 1 non-null cells, holding 12 (text version, image version, svg version)

Note that

* Our CList now contains two Cells objects, the second being null,
* first now refers a Cell that actually contains a value, 12.

We can add another element to our list using the following statement:

myList1.AddF(10);

and our myList1 becomes:

A diagram for a CList with 2 non-null cells, holding 10 and 12 (text version, image version, svg version)

Note that the element is added *to the left*, that is, the CList “grows” from the left using the AddF method.

## More Advanced Methods and Properties

### IsEmpty Method and Property

We will often need to test if a CList is empty, so we introduce a method to perform this test easily:

public bool IsEmpty()  
 {  
 return (first == null);  
 }

Note that we could have decided to implement this test as a property, using for example

public bool IsEmpty  
{  
 get {return first == null;  
}

Of course, such property would not have any set method.

### AddL Method

Our AddF method allows to add elements to our CList “to the left”, but we may want to add elements to *the end* of the list (that is, to its right). We can achieve this with the following method:

public void AddL(T dataP)  
 {  
 if (IsEmpty())  
 AddF(dataP);  
 else  
 {  
 Cell cCell = first;  
 while (cCell.Next != null)  
 // As long as the cCell Cell has a neighbour…  
 {  
 cCell = cCell.Next;  
 // We move the cCell cell to this neighbour.  
 }  
 // When we are done, we can insert the cell.  
 cCell.Next = new Cell(dataP, null);  
 }  
 }

The method proceeds as follows:

* If the CList is empty, then we can use AddF, since adding to the right or to the left will have the same outcome,
* If it is not, we need to find the “last” Cell. Finding the “last” Cell is easy: it is the only one whose Next is null. We move through the list as follows:
* Cell cCell = first;  
  while (cCell.Next != null)  
  {  
   cCell = cCell.Next;  
  }
* The idea being that as long as the current Cell contains a Next that is not null, then we follow it and make the next cell our current Cell.
* Once we found this “last” Cell, we update its Next so that it refers to a new Cell object that contains the data we wanted to insert (dataP), and does not refers to any other Cell (hence, its Next is null).

### Size Property

It can be useful to easily know how many non-null Cells are contained within a CList: this is the equivalent of the Count property from [C#’s List](https://learn.microsoft.com/en-us/dotnet/api/system.collections.generic.list-1.count?view=net-9.0#system-collections-generic-list-1-count). Of course, this property should only contain a get, since the Size will be computed based on the number of elements contained in the CList, so that we get:

public int Size  
 {  
 get  
 {  
 int size;  
 if (IsEmpty())  
 {  
 size = 0;  
 }  
 else  
 {  
 size = 1;  
 Cell cCell = first;  
 while (cCell.Next != null)  
 // As long as the cCell Cell has a neighbour…  
 {  
 cCell = cCell.Next;  
 // We move the cCell cell to this neighbour.  
 size++;  
 }  
 }  
 return size;  
 }  
 }

This property uses a loop very similar to the AddL method to traverse the CList, but it keeps track of how many elements were traversed using a size index. Note that it begins by testing if the CList is empty: otherwise, the condition cCell.Next != null would throw an exception with an empty CLists, since null does *not* posses a Next property!

### ToString Method

We also implement a ToString method that returns a table looking like an array:

public override string ToString()  
 {  
 string returned = "———";  
 // Line above the table  
 for (int i = 0; i < Size; i++)  
 {  
 returned += "————";  
 }  
 returned += "\n| ";  
 // Content of the CList  
 Cell cCell = first;  
 while (cCell != null)  
 {  
 returned += $"{cCell.Data} | ";  
 cCell = cCell.Next;  
 }  
 returned += "\n———";  
 // Line below the table  
 for (int i = 0; i < Size; i++)  
 {  
 returned += "————";  
 }  
 return returned + "";  
 }

Our previous myList1 would then be displayed as follows:

———————————  
| 10 | 12 |  
———————————

Observe that:

* We use the Size property to draw the lines above and below our table, repeating the same code twice.
* The string "———" is added once to the line above and once to the line below the table to improve the final rendering.
* Our loop uses the cCell != null condition, testing if a Cell is null before trying to access its Data property. Note that cCell will hold null at some point, but no exception will be raised since our condition makes the loop terminates when that happens.
* Attempting to call ToString with a CList containing only the null Cell would return
* ———  
  |  
  ———
* which is not very elegant, but at least no exception is raised.

## Additional Methods and Properties

Additional methods are shared in the following source code:

public T Access(int index)  
 {  
 if (index >= Size)  
 {  
 throw new IndexOutOfRangeException();  
 }  
 else // Some IDE will flag this "else" as redundant.  
 {  
 int counter = 0;  
 Cell cCell = first;  
 while (counter < index)  
 {  
 cCell = cCell.Next;  
 counter++;  
 }  
 return cCell.Data;  
 }  
 }  
  
 /\*  
 \* We can write four methods to  
 \* remove elements from a CList.  
 \* - One that clears it entirely,  
 \* - One that removes the first cell,  
 \* - One that removes the last cell,  
 \* - One that removes the nth cell, if it exists,  
 \*/  
  
 public void Clear()  
 {  
 first = null;  
 }  
  
 public void RemoveF()  
 {  
 if (!IsEmpty())  
 first = first.Next;  
 }  
  
 public void RemoveL()  
 {  
 if (!IsEmpty())  
 {  
 if (first.Next == null)  
 {  
 RemoveF();  
 }  
 else  
 {  
 Cell cCell = first;  
 while (  
 cCell.Next != null && cCell.Next.Next != null  
 )  
 {  
 cCell = cCell.Next;  
 }  
 cCell.Next = null;  
 }  
 }  
 }  
  
 // Method to remove the nth element if it exists.  
 public void RemoveI(int index)  
 {  
 if (index > Size)  
 {  
 throw new IndexOutOfRangeException();  
 }  
 else // Some IDE will flag this "else" as redundant.  
 {  
 int counter = 0;  
 Cell cCell = first;  
 while (counter < index - 1)  
 {  
 cCell = cCell.Next;  
 counter++;  
 }  
 cCell.Next = cCell.Next.Next;  
 }  
 }  
  
 // Method to obtain the largest  
 // number of consecutive values  
 // dataP.  
  
 public int CountSuccessive(T dataP)  
 {  
 int cCount = 0;  
 int mCount = 0;  
 Cell cCell = first;  
 while (cCell != null)  
 {  
 if (cCell.Data.Equals(dataP))  
 {  
 cCount++;  
 }  
 else  
 {  
 if (cCount > mCount)  
 {  
 mCount = cCount;  
 }  
 cCount = 0;  
 }  
 cCell = cCell.Next;  
 }  
 if (cCount > mCount)  
 {  
 mCount = cCount;  
 }  
 return mCount;  
 }  
  
 // Method to remove at a particular index  
 // Very similar to RemoveI, simply  
 // implemented with a different philosophy.  
 public void RemoveAt(int index)  
 {  
 if (index >= 0 && index < Size)  
 {  
 if (index == 0)  
 RemoveF();  
 else if (index == (Size - 1))  
 RemoveL();  
 else  
 {  
 Cell cCell = first;  
 for (int i = 0; i < index - 1; i++)  
 {  
 cCell = cCell.Next;  
 }  
 cCell.Next = cCell.Next.Next;  
 }  
 }  
 else  
 throw new ArgumentOutOfRangeException();  
 }  
  
 // Method to reverse a list  
 public void Reverse()  
 {  
 Cell cCell = first;  
 Cell previous = null;  
 Cell next;  
 while (cCell != null)  
 {  
 next = cCell.Next;  
 cCell.Next = previous;  
 previous = cCell;  
 cCell = next;  
 }  
 first = previous;  
 }  
  
 // Method to look for a specific value (recursively)  
 public bool Find(T dataP)  
 {  
 return Find(first, dataP);  
 }  
  
 private bool Find(Cell cCell, T dataP)  
 {  
 if (cCell == null)  
 return false;  
 else if (cCell.Data.Equals(dataP))  
 return true;  
 else  
 return Find(cCell.Next, dataP);  
 }  
  
 // Method to obtain the last index  
 // of dataP.  
 public int LastIndexOf(T dataP)  
 {  
 int index = 0,  
 lastIndex = -1;  
 Cell cCell = first;  
 while (cCell != null)  
 {  
 if (cCell.Data.Equals(dataP))  
 {  
 lastIndex = index;  
 }  
 index++;  
 cCell = cCell.Next;  
 }  
 return lastIndex;  
 }  
  
 // Recursive method to obtain the  
 // frequency of dataP  
 public double Frequency(T dataP)  
 {  
 if (Size == 0)  
 throw new ArgumentNullException();  
 else  
 return Count(dataP, first) / (double)Size;  
 }  
  
 private int Count(T dataP, Cell pTmp)  
 {  
 if (pTmp == null)  
 return 0;  
 else if (pTmp.Data.Equals(dataP))  
 return 1 + Count(dataP, pTmp.Next);  
 else  
 return 0 + Count(dataP, pTmp.Next);  
 }

[*(Download this code)*](https:/princomp.github.io/code/projects/CList.zip)

# Over and Underflow

## Overflow

* Assume a car has a 4-digit odometer, and currently, it shows 9999. What does the odometer show if you drive the car another mile? As you might guess, it shows 0000 while it should show 10000. The reason is the odometer does not have a counter for the fifth digit. Similarly, in C#, when you do arithmetic operations on integral data, the result may not fit in the corresponding data type. This situation is called an **overflow** error.
* In an unsigned data type variable with bits, we can store the numbers from 0 to . In signed data type variables, the high order bit represents the sign of the number as follows:
* 0 means zero or a positive value
* 1 means a negative value
* With the remaining bits, we can represent values. Hence, considering the sign bit, we can store a number from to in the variable.
* In some programming languages like C and C++, overflow errors cause undefined behavior, and can crash your program. In C#, however, the extra bits are just ignored, and the program will continue executing even though the value in the variable may not make sense. If the programmer is not careful to check for the possibility of overflow errors, they can lead to unwanted program behavior and even severe security problems.
* For example, assume a company gives loans to its employee. Couples working for the company can get loans separately, but the total amount cannot exceed $10,000. The following program looks like it checks loan requests to ensure they are below the limit, but it can be attacked using an overflow error. (This program uses notions you may have not studied yet, but that should not prevent you from reading the source code and executing it.)

using System;  
  
class Program  
{  
 static void Main()  
 {  
 uint n1,  
 n2;  
  
 Console.WriteLine(  
 "Enter the requested loan amount for the first person:"  
 );  
 n1 = uint.Parse(Console.ReadLine());  
  
 Console.WriteLine(  
 "Enter the requested loan amount for the second person:"  
 );  
 n2 = uint.Parse(Console.ReadLine());  
  
 if (n1 + n2 < 10000)  
 {  
 Console.WriteLine($"Pay ${n1} to the first person");  
 Console.WriteLine($"Pay ${n2} to the second person");  
 }  
 else  
 {  
 Console.WriteLine(  
 "Error: the sum of the loans exceeds the maximum allowance."  
 );  
 }  
 }  
}

* If the user enters 2 and 4,294,967,295, we expect to see the error message (“Error: the sum of loans exceeds the maximum allowance.”). However, this is not what will happen, and the request will be accepted even though it should not have. The reason can be explained as follows:
* uint is a 32-bit data type.
* The binary representation of 2 and 4,294,967,295 are 00000000000000000000000000000010 and 11111111111111111111111111111111.
* Therefore, the sum of these numbers should be 100000000000000000000000000000001, which needs 33 bits.
* Nevertheless, there are only 32 bits available for the result, and the extra bits will be dropped, so the result will be 00000000000000000000000000000001. This is less than 10,000, so the program will conclude that the sum of the loan values is less than 10,000.

## Underflow

* Sometimes, the result of arithmetic operations over floating-point numbers is smaller than the minimum value that can be stored in the corresponding data type. This problem is known as the **underflow** problem.
* In C#, in case of an underflow, the result will be zero.
* For example, the smallest value that can be stored in a float variable is . If we attempt to divide this value by 10, the variable will get the value 0, not :

using System;  
  
class Program  
{  
 static void Main()  
 {  
 float myNumber;  
 myNumber = 1E-45f;  
 Console.WriteLine(myNumber); //outputs 1.401298E-45  
 myNumber = myNumber / 10;  
 Console.WriteLine(myNumber); //outputs 0  
 myNumber = myNumber \* 10;  
 Console.WriteLine(myNumber); //outputs 0  
 myNumber = (1E-45f / 10) \* 10;  
 Console.WriteLine(myNumber); //outputs 0  
 }  
}

* An underflow error can result in “losing” data in the middle of a series of operations: even if you immediately multiply by 10 again, the intermediate result was less than , so the final result is still 0.

# Random

* Random Number Generation
  + Produce a number within some bounds following some statistical rules.
  + A true random number is a number that is **nondeterministically** selected from a set of numbers wherein each possible selection has an equal probability of occurrence.
  + Usually in computer science we contend with **pseudo-random** numbers. These are not truly nondeterministic, but an approximation of random selection based on some algorithm.
  + Since pseudo-random selections are “determined” by an algorithm, or set of rules, they are technically **deterministic**.
* Random Class in C#
  + Instantiate a random number generator and use to select numbers:
  + Random rand = new Random();  
    Random randB = new Random(seed\_int);
  + Notice that we can create a generator with or without an argument. The argument is called a **seed** for the generator.
  + A seed tells the generator where to start its sequence. Using the same seed will always reproduce the same sequence of numbers.
  + The default constructor still has a seed value, but it is a hidden value pulled from the clock time during instantiation.
  + Time-based seeds only reset approximately every 15 milliseconds.
  + The random class is not “random enough” for cryptography.
  + For cryptographic randomness, use the [RNGCryptoServiceProvider](https://docs.microsoft.com/en-us/dotnet/api/system.security.cryptography.rngcryptoserviceprovider?view=net-5.0) class or [System.Security.Cryptography.RandomNumberGenerator](https://docs.microsoft.com/en-us/dotnet/api/system.security.cryptography.randomnumbergenerator?view=net-5.0).
* Using Random
  + Next() method returns a pseudo-random number between 0 and 2,147,483,647 (max signed int), inclusive.
  + By default, the number is always non-negative and within that range.
  + int randomInt = rand.Next();
  + What if we wanted to create a random number between 0 and 100?
  + We could use rand.Next() and then use modulo to cut down the answer range!
  + Alternatively, we could give the Next() method an int argument to set a ceiling.
  + int randomUpto100 = rand.Next(101);
  + The ceiling value is **exclusive**, so remember to use one number higher than what you want to be your max number.
  + We can also pass two arguments in order to set a range for the values.
  + int random50to100 = rand.Next(50,101);
  + The ceiling value is still exclusive, but the floor is **inclusive**.
  + NextDouble() returns a **normalized** value (value between 0.0 and 1.0 inclusive).
  + What if we want a different range? Adjust with math!
  + double randNeg2to3 - (rand.NextDouble()\*5)-2;
  + NextBytes() method takes a byte array as an argument and generates a random byte value for each index.
  + Remember, a byte has an unsigned value between 0 and 255 inclusive.
  + byte[] byteArray = new byte[10];  
    rand.NextBytes(byteArray);
* Creating Random Strings
  + What if we want to construct random strings made of a, b, c, and d?
  + Other techniques are available, but we can use a loop and switch!
  + Random rand = new Random();  
    string answer = "";  
    int selection = 0;  
      
    for(int i = 0; i < 10; i++)  
    {  
     selection = rand.Next(4);  
     switch(selection){  
     case(0):  
     answer+="a";  
     break;  
     case(1):  
     answer+="b";  
     break;  
     case(2):  
     answer+="c";  
     break;  
     default:  
     answer+="d";  
     break;  
     }  
    }

# Exceptions

## Introduction

* At *execution time* programs can run into unspecified behavior, such as
  + having to divide by zero,
  + having to access an array at an index greater than its length.
* For example, the following instructions would compile just fine, but *at execution time* the program would “explode”:
* int zero = 0;  
  Console.WriteLine($"Let's divide by zero: {1 / zero}.");
* int[] test = new int[2];  
  test[2] = 3;
  + In the first case, a “System.DivideByZeroException has been thrown” error message would be displayed.
  + In the second case, a “System.IndexOutOfRangeException has been thrown” error message would be displayed.
  + Those are examples of exceptions [thrown by operations](https://learn.microsoft.com/en-us/dotnet/csharp/language-reference/language-specification/exceptions#215-common-exception-classes).
* Methods can also throw exceptions. For example, the following statement:
* int x = int.Parse("This is not a number.");
* will display a “System.FormatException has been thrown” error message. This is because [the Parse method can *throw an exception*](https://learn.microsoft.com/en-us/dotnet/api/system.int32.parse?view=net-8.0#system-int32-parse(system-string)).
* Of course, a programmer would not *purposely* introduce such strange instructions in their code, but they may arise after interacting with the “outside world”, that is, a user, file, or other external factor.
* C# allows *exception handling*, which are ways of recovering when such exceptions are thrown, so that the program can keep on executing. Stated differently, they instruct the program what to do, for example, if it is asked to perform a division by 0. This is handled by catch blocks.
* C# also allows finally blocks, which contain code executed unconditionally, that is, regardless of whether an exception was thrown or not.

## Syntax and Rules for try-catch-finally Statements

* In a first approximation, the syntax of a try-catch-finally statement is as follows:
* try{  
   <statement block 1>  
  }  
  catch{  
   <statement block 2>  
  }  
  finally{  
   <statement block 3>  
  }
* When executed, <statement block 1> will be executed statement by statement. If, at any point, one of the statement in <statement block 1> throws an exception, then the rest of the statements in <statement block 1> will be discarded and <statement block 2> will execute. After all of the statements in <statement block 1> have executed, or after all of the statements in <statement block 2> have executed, then <statement block 3> will execute.
* A simple example is
* try  
  {  
   Console.WriteLine("Enter a number.");  
   Console.WriteLine($"Your number is {int.Parse(Console.ReadLine())}.");  
  }  
  catch  
  {  
   Console.WriteLine("Something was off.");  
  }  
  finally  
  {  
   Console.WriteLine("Did it work?");  
  }
  + If the user enters a string that contains only numbers (say, “10”), then the program will display “Your number is 10.” then “Did it work?”.
  + If the user enters a string that does *not* contain only numbers (say, “No”), then the program will display “Something was off.” then “Did it work?”.
* Both the catch and the finally parts of the statement are optional: they can be both present, or only one can occur in the try block statement (however, you have to have one or the other).
* A try block can have multiple catches, as follows:
* try  
  {  
   Console.WriteLine("Enter a number");  
   int uInput = int.Parse(Console.ReadLine());  
   Console.WriteLine($"Your number is {uInput}.");  
   Console.WriteLine($"Ten divided by your number is {10 / uInput}.");  
    
  }  
  catch (DivideByZeroException)  
  {  
   Console.WriteLine("You tried to divide by zero.");  
  }  
  catch (FormatException)  
  {  
   Console.WriteLine("You have tried to convert a string "  
   + " containing non-numerical characters to a number.");  
  }  
  finally  
  {  
   Console.WriteLine("Did it work?");  
  }
  + This allows a more fine-grained handling of the exceptions that can be thrown.
  + In the example, if a DivideByZeroException exception is thrown, it is because the user entered “0” and the operation {10 / uInput} failed. In this case, we can display an appropriate error message (“You tried to divide by zero”).
  + In the example, if a FormatException exception is thrown, it is because the user entered a string containing non-numerical characters, and we can similarly return an appropriate error message.
  + Writing catch{…} is the same as catch (Exception){…}: by default, a catch block catches all the exceptions that can be thrown, not the exceptions of a particular class. Note that, if specifying multiple catch blocks, the order matters, as a catch (Exception), if placed first, will always execute before the catch blocks put after.

## Exception Class and Objects

* Technically speaking, an exception is an object in a particular class that inherits from the [exception class](https://learn.microsoft.com/en-us/dotnet/standard/exceptions/exception-class-and-properties).
* We can assign an identifier to it in the catch block, to be able to access some of its properties, such as the Message and a StackTrace properties.
* For example, the IndexOutOfRangeException object returned when trying to access an array outside of its bound can be named ex and used to display particular information:
* try  
  {  
   int[] test = new int[10];  
   for (int i = 0; i <= test.Length; i++)  
   {  
   test[i] = i;  
   }  
  }  
  catch (IndexOutOfRangeException ex)  
  {  
   Console.WriteLine(ex.Message);  
   Console.WriteLine(ex.StackTrace);  
  }
  + When the statement test[10] = 10; gets executed, the exception is thrown, named ex, and we display its message (“Index was outside the bounds of the array.”) and StackTrace (“at Program.Main (System.String[] args) [0x0000f] in <path>/Program.cs:<line>”, with <path> the path of the Program.cs file, and <line> the line where the error occurs).

## Purpose of the finally Block

* The difference between
* try{  
   <statement block 1>  
  }  
  catch{  
   <statement block 2>  
  }  
  finally{  
   <statement block 3>  
  }
* and
* try{  
   <statement block 1>  
  }  
  catch{  
   <statement block 2>  
  }  
  <statement block 3>
* is that in the second case, <statement block 3> may be skipped if <statement block 1> or <statement block 2> return a value, throw an exception that is not caught, or break the flow of control (using for example break;). In the first case, <statement block 3> will *always*[[15]](#footnote-15) get executed, no matter which block gets executed and even if it breaks the control flow or throws another exception.
* For example,
* using System;  
    
  class Game  
  {  
   public static bool Guess(string guessP)  
   {  
   const int VALUE\_TO\_GUESS = 12;  
   try  
   {  
   int guessV = int.Parse(guessP);  
   if (guessV == VALUE\_TO\_GUESS)  
   {  
   Console.WriteLine("You guessed it!");  
   return true;  
   }  
   else  
   {  
   Console.WriteLine("Try again!");  
   return false;  
   }  
   }  
   catch (FormatException)  
   {  
   Console.WriteLine(  
   "Please, provide a string containing only numbers"  
   );  
   return false;  
   }  
   finally  
   {  
   Console.WriteLine("Thank you for playing!");  
   }  
   }  
  }
* [*(Download this code)*](https:/princomp.github.io/code/projects/Game.zip) will always display “Thank you for playing!”. If this last statement was *not* in the finally block, but was simply inserted after the try-catch statement, then this message would actually never be displayed.

## Scoping in try-catch-finally Statements

* Understanding the scope of statements in try-catch-finally statements can be tricky.
* The general rules are:
  + Variables declared in try, catch or finally blocks will not be accessible outside of them,
  + Variables whose values are set in the try block will keep the values they had on the specific line where the try block threw an exception.
* For example, in the following code,
* int zero = -1;  
  try  
  {  
   zero = 0;  
   int x = 1 / zero;  
   zero = 2;  
  }  
  catch (DivideByZeroException)  
  {  
   Console.WriteLine("You tried to divide by " + zero + ".");  
   zero = 3;  
  }  
  finally  
  {  
   Console.WriteLine("The variable holds " + zero + ".");  
  }
  + This program will display
  + You tried to divide by 0.  
    The variable holds 3.
  + The variable x would not be accessible to the catch or finally blocks.
  + If we were to remove the zero = 0; statement, then the program would display “The variable holds 2.”. This is because the statement zero = 3; only executes if the exception is thrown; similarly, the statement zero = 2 only executes if the exception *isn’t* thrown in the line above it.

## When To Use try-catch and When To Use TryParse?

* If something goes wrong in a method, that method can either return some error code or throw an exception.
* Returning an error code means possibly cluttering the signature of the method with some extra parameters, as in the TryParse methods.
* TryParse is “baking in” a way of signaling that something went wrong because
  1. This type of error is simple, common, and predictable,
  2. It decided not to care about *why* the parsing fails (it can be either because the input is null, because it is not in valid format, or because it produces an overflow).
* However, exceptions can handle those cases differently thanks to different catch blocks:
* Console.WriteLine("Test with" +  
   "\n\t- nothing (ctrl + d on linux, ctrl + z on windows), " +  
   "\n\t- \"No\"," +  
   "\n\t- " + int.MaxValue + "+ 1 = 2147483648.");  
  try  
  {  
   int.Parse(Console.ReadLine());  
  }  
  catch (ArgumentNullException)  
  {  
   Console.WriteLine("No argument provided.");  
  }  
  catch (FormatException)  
  {  
   Console.WriteLine("The string does not contain only number characters.");  
  }  
  catch (OverflowException)  
  {  
   Console.WriteLine("The number is greater than what an integer can store.");  
  }
* So, in summary, TryParse is in general better if there is no need to handle the different exceptions differently.

## Throwing an Exception

* You can explicitly throw an exception by
  + Creating an Exception object,
  + Throwing it, using the throw keyword.
* For example, the property setter in the following class can explicitly throw an ArgumentOutOfRangeException object if we try to create a Circle object with a negative diameter:
* ﻿using System;  
    
  class Circle  
  {  
   private decimal diameter;  
   public decimal Diameter  
   {  
   get { return diameter; }  
   set  
   {  
   if (value <= 0)  
   {  
   throw new ArgumentOutOfRangeException();  
   }  
   else  
   {  
   diameter = value;  
   }  
   }  
   }  
    
   public Circle(decimal dP)  
   {  
   Diameter = dP;  
   }  
    
   public override string ToString()  
   {  
   return "Diameter: " + diameter;  
   }  
  }
* To use this class properly, every time the Diameter value is set (using the set accessor, possibly *via* the constructor), a try-catch statement should be used to handle a possible exception, with possibly a loop around it, as follows:
* ﻿using System;  
    
  class Program  
  {  
   static void Main(string[] args)  
   {  
   Circle circle1 = new Circle(1);  
   Console.WriteLine(circle1);  
    
   try  
   {  
   circle1 = new Circle(-10);  
   Console.WriteLine("circle1: " + circle1);  
   }  
   catch (ArgumentOutOfRangeException)  
   {  
   Console.WriteLine($"Error: value was out of range.");  
   }  
   Console.WriteLine(circle1);  
    
   bool circle\_modified = false;  
   do  
   {  
   try  
   {  
   Console.WriteLine("Enter the circle new diameter.");  
   int uInput = int.Parse(Console.ReadLine());  
   circle1.Diameter = uInput;  
   Console.WriteLine(circle1);  
   circle\_modified = true;  
   }  
   catch (ArgumentOutOfRangeException)  
   {  
   Console.WriteLine(  
   $"Error: value was out of range."  
   );  
   }  
   catch  
   {  
   Console.WriteLine("Something went wrong.");  
   throw;  
   }  
   } while (!circle\_modified);  
   }  
  }
* In the last catch block above, the throw; (without argument) will pass the exception to the calling environment. It is indeed possible to catch the exception, do something with it (typically, log it or display an error message), and then “pass” that exception to the surrounding environment.

# Reference Types

## Motivation

There is a fundamental difference between *value types* and *reference types* in C#. For example, compare:

int x = 10;  
int y = x;  
y = 11;  
Console.WriteLine($"x is {x}, y is {y}.");  
// Displays "x is 10, y is 11.".

and

int[] a = { 10 };  
int[] b = a;  
b[0] = 11;  
Console.WriteLine($"a[0] is {a[0]}, b[0] is {b[0]}.");  
// Displays "a[0] is 11, b[0] is 11.".

In the first case (with ints), the value of x will remain 11, but in the second (with arrays of ints), a[0] will now contain 11 as well. That is because when y = x was executed, the *value* of x was copied, but when b = a is executed, the *reference to the array* was copied.

All the built-in types are *value types*: numerical types, char and bool contains *values*. On the other hand, objects, string and arrays, for example, are *reference types*.

## null Value

Reference types can contain a special value, called null, that intuitively means that it references nothing. It can be used as follows:

int[] c = null;

Any reference type must be handled with great care, since for example

Console.WriteLine(c.Length);

would compile but would throw a NullReferenceException exception (a null reference doesn’t have any Length property!).

Three operators allows to simplify testing whenever a variable holds null and behave accordingly, we detail them below.

## null-Conditional Operator

The null-conditional operator ? allows to test if a variable holds null and to avoid some NullReferenceException.

For example,

Console.WriteLine($"Length of a is: {a?.Length}.");

will display “Length of a is: 1.” if a holds a reference to an array of size 1, and “Length of a is: .” if a holds a null. Stated differently, a?.Length evaluates to the size of the array referenced by a if it exists, to null otherwise.

One can similarly write a?[0] to either get a null (if a itself is null) or the value at the first index of the array referenced by a.

### null-Coalescing Operator

The null-coalescing operator ?? allows to assign a reference *if it is not null*, and to assign a default value otherwise.

For example,

string s1 = null;  
string s2 = s1 ?? "nothing";  
Console.WriteLine($"s1 is {s1}, s2 is {s2}.");

will display “s1 is , s2 is nothing.”: the assignment s2 = s1 ?? "nothing" “skipped” the value s1 since it was null and used "nothing" instead.

## null-Coalescing Assignment Operator

The null-coalescing assignment operator ??= allows to re-assign a variable if it is null.

For example,

s1 ??= "default";

will assign "default" to s1 if it is null, leave its value unchanged otherwise. Note that this operator is available only starting with C# 8.0.

### Nullable value types

It is also possible to make a value type *nullable*, so that it can contains the null value. For example,

int[] a = null;  
int aLength = a?.Length;

is not valid since a?.Length will evaluate to null, and an int variable cannot contain a reference!

It is possible, however, to make aLength *nullable*, using the ? operator:

int[] a = null;  
int? aLength = a?.Length;

This way, aLength can contain either an integer value, or the null reference.

To “convert” a nullable value type back into a “non-nullable” value type can be done using the null-coalescing operator ??. For example,

int d = aLength ?? -1;

will assign aLength to d if it is not null, and -1 otherwise: note that either way, d will end up containing a non-null value.

## Testing for Equality

### Motivation

A great care is required when comparing *references*, since one need to make sure that

* null is accounted for,
* the comparison is “shallow” only if we want it to.

A “shallow” comparison compares only the “surface” of reference variables, as follows:

int[] a = { 10 };  
int[] b = a;  
int[] c = { 10 };  
  
if (a == b){ Console.WriteLine("a and b refers the same array."); }  
if (a != c){ Console.WriteLine("a and c refers different arrays."); }

Both tests would evaluate to true, since a and b do indeed refer to the same array, while a and c refer to different arrays. In general, this is not what is intended when comparing objects or arrays: we want to know if *what they refer to* is identical.

### Comparing Arrays

To compare arrays while accounting for possible null values, a great care is needed. One can write a method as follows:

public static bool SameArray<T>(T[] arP1, T[] arP2)  
{  
 if (arP1 == null && arP2 == null) { return true; }  
 else if (arP1 == null || arP2 == null) { return false; }  
 else if (arP1.Length != arP2.Length) return false;  
 else {  
 for (int i = 0; i < arP1.Length; i++)  
 {  
 if (!Equals(arP1[i], arP2[i])) return false;  
 }  
 }  
 return true;  
}

So that, if SameArray is passed…

* … two null references, it will return true since, indeed, the arguments refers to “the same” array, which does not exist,
* … a null reference and a reference that is not null, it will return false, as a non-existent array is not the same as an existing array,
* … two arrays of different size, it will return false,
* … two arrays of the same size, where every single value is the same, it will return true.

Note that

* for the first two cases, one may decide to use throw new ArgumentNullException() instead, because it could be argued comparing null references is, precisely, shallow.
* it is ok to use arP1.Length and arP2.Length in our code, since we know at that point that neither arP1 nor arP2 is null.
* we cannot use if (arP1[i] != arP2[i]) as C# doesn’t “know” by default that what we use for T will accept this operator. Instead, we have to use the “generic” Equals method.

## Passing Arguments

### Motivation

Consider the following “swapping” method and a Main method calling it:

using System;  
  
class Program  
{  
 static void Main()  
 {  
 int a = 10;  
 int b = 20;  
 Console.WriteLine(  
 $"Before swap: a holds {a}, b holds {b}."  
 );  
 Swap(a, b);  
 Console.WriteLine(  
 $"After swap: a holds {a}, b holds {b}."  
 );  
 }  
  
 static void Swap(int a, int b)  
 {  
 int temp = a;  
 a = b;  
 b = temp;  
 Console.WriteLine(  
 $"Inside swap: a holds {a}, b holds {b}."  
 );  
 }  
}

This program would display:

Before swap: a holds 10, b holds 20.  
Inside swap: a holds 20, b holds 10.  
After swap: a holds 10, b holds 20.

As we can see, the values held by the variables a and b are correctly swapped by the Swap method, but this change is not “permanent”: once the Swap method completed, a and b still have their “old” values inside Main.

Since a method cannot return two values, making that change permanent is difficult. A solution could be designed using arrays for example, but it would require additional manipulation in the Main method. Instead, one can use references to pass *the reference to the variables instead of their values*.

### ref Keyword

The ref keyword can be used to pass the reference to a variable, as follows:

using System;  
  
class Program  
{  
 static void Main()  
 {  
 int a = 10;  
 int b = 20;  
 Console.WriteLine(  
 $"Before swap: a holds {a}, b holds {b}."  
 );  
 Swap(ref a, ref b);  
 Console.WriteLine(  
 $"After swap: a holds {a}, b holds {b}."  
 );  
 }  
  
 static void Swap(ref int a, ref int b)  
 {  
 int temp = a;  
 a = b;  
 b = temp;  
 Console.WriteLine(  
 $"Inside swap: a holds {a}, b holds {b}."  
 );  
 }  
}

Note that the change with the previous code is minimal: only the keyword ref is added:

* In front of the datatype of the arguments in Swap’s header,
* In front of the name of the variables when the Swap method is called.

Note that *both* edits are required: the first one stipulates that the Swap method expects *references*, and the second one stipulates that the *references* are passed.

This program would display:

Before swap: a holds 10, b holds 20.  
Inside swap: a holds 20, b holds 10.  
After swap: a holds 20, b holds 10.

Indeed, since *the reference* was passed, Swap stored the new values *in the same variables* a *and* b, making the swapping “permanent”.

### out Keyword

In some cases, one may want to pass a reference to a method simply as an address where a value must be stored. The benefit is that this reference does not need to contain a value before being passed to a method.

For example, consider:

static void SetToRandom(ref int a)  
{  
 Random gen = new Random();  
 a = gen.Next(10);  
}

that sets the value of a reference to a random number between 0 and 9 (both included).

It can**not** be called as follows:

int a; // This code will not compile  
SetToRandom(ref a);

Because C#’s compilation will return the error message “Use of unassigned local variable ‘c’”. Indeed, SetToRandom expects the argument to already holds a reference to a value, even if it has no use for it.

A better alternative is to use the out keyword:

using System;  
  
class Program  
{  
 static void Main()  
 {  
 int a;  
 SetToRandom(out a);  
 Console.WriteLine(a);  
 }  
  
 static void SetToRandom(out int a)  
 {  
 Random gen = new Random();  
 a = gen.Next(10);  
 }  
}

Note that:

* The keyword out is similarly added in the header of the method and when the argument is passed,
* The variable a is *not* given a value before being passed to the method.

Summing up, the difference between ref and out is that out does not require the reference to point to an actual value *entering into the method* but *it must hold a value by the time we exit the method*.

To illustrate this last point, observe that

static void Dummy(out int a)  
{  
 Console.WriteLine("Hi!");  
}

would not compile, as C# would give back a message “The out parameter ‘a’ must be assigned to before controls leaves the current method”: an argument passed using the keyword out **must** be initialized in the body of the method.

# Files

The code for this lecture [is available in this archive](https:/princomp.github.io/code/projects/FileDemo.zip).

## Motivation

Files are useful for permanency: when a program terminates, all the objects created, strings entered by the user, and even the messages displayed on the screen, are lost. *Saving* some information as files allows to retrieve this information after the program terminates, possibly using a different tool. *Retrieving* information from a file allows to continue works that was started by a different program, or to use a better-suited tool to carry on some task (typically, counting the number of words in a document).

This lecture is concerned with files: how to write into them, how to read from them, how to make sure that our program does not throw exceptions when dealing with “I/O” (read: input / output) operations? We will only consider *textual* files, with the .txt extension, for now.

## Warm-Up: Finding a Correct Path

Each file has a (full, or absolute) *path*, which is a string describing where it is stored: it is made of a directory path and a file (or base) name. Paths are complicated because they can

* Vary with the operating system (windows uses \ as a path separator, but macOS and Unix systems use /),
* Vary with the user (windows store information in the C:\Users\<username>\ folder, that will change based on your username),
* Vary with the language (windows calls the “Downloads” folder “Overførsler” in Danish),
* Point to a folder that the current user is not allowed to explore (/root/ in Unix systems),
* Not exist,
* etc.

A fairly reliable way of handling this diversity is to select the folder /bin/Debug naturally present in your solution (it is where the executable is stored). We can access its directory path using:

string directoryPath = AppDomain  
 .CurrentDomain  
 .BaseDirectory;  
 Console.WriteLine(  
 "Directory path is " + directoryPath + "."  
 );

On most Unix systems, this would display at the screen something like

~/source/code/projects/FileDemo/FileDemo/bin/Debug/

To add to this directory path the file name, we will be using the Combine method from the Path class, as follows:

string filePath = Path.Combine(  
 directoryPath,  
 "Hello.txt"  
 );  
 Console.WriteLine("File path is " + filePath + ".");

| ⚠ Warning |
| --- |
| Unless otherwise stated, we will always use this folder in our examples. |

## Writing Into a File

Writing into a file is done using the StreamWriter class and a couple of methods:

* a constructor, that takes a string describing a path as an argument,
* the WriteLine method, that write its string argument to the file, followed by a new line,
* the Write method, that write its string argument to the file,
* the Close method, that closes the file.

Even if we will not go into details about the role of the Close method, it is extremely important and should never be omitted.

As an example, we can create a HelloWorld.txt file containing

Hello World!!  
From the StreamWriter class0123456789

using the following code:

StreamWriter sw = new StreamWriter(filePath);  
 sw.WriteLine("Hello World!!");  
 sw.Write("From the StreamWriter class");  
 for (int x = 0; x < 10; x++)  
 {  
 sw.Write(x);  
 }  
 sw.Close();

## Reading From a File

Reading from a file is very similar to writing from a file, as we are using a StreamReader class and a couple of methods:

* a constructor, that takes a string describing a path as an argument,
* the ReadLine method, that read the current line of the file and move the cursor to the next line,
* the Close method, that closes the file.

The Close method is similarly important and should never be omitted.

As an example, we can open a file located at filePath and display its content at the screen using:

string line;  
 StreamReader sr = new StreamReader(filePath);  
 line = sr.ReadLine();  
 while (line != null)  
 {  
 Console.WriteLine(line);  
 line = sr.ReadLine();  
 }  
 sr.Close();

## What Can Go Wrong?

When manipulating files, *many* things can go wrong.

### What if we are trying to read a file that does not exist?

If the StreamReader constructor is given a path to a file that does not exist, it will raise an exception (discussed [below](#many-things-can-go-wrong)). We can catch this exception, but a better mechanism is to simply warn the user, using the File.Exists method that return true if its string argument points to a file, false otherwise.

if (!File.Exists(filePath))  
 {  
 Console.WriteLine("File does not exist.");  
 }

### What if we are trying to write into a file that already exist?

A dual problem is if the path we are using as an argument to the StreamWriter constructor points to a file that already exists: by default, that file will be overwritten. An alternative mechanism is to use the overloaded StreamWriter constructor [that additionally takes a bool as argument](https://learn.microsoft.com/en-us/dotnet/api/system.io.streamwriter.-ctor?view=net-8.0#system-io-streamwriter-ctor(system-string-system-boolean)): if the bool is set to true, then the new content will be *appended* into the existing file instead of overwriting it.

Hence, we can use the following:

StreamWriter sw = new StreamWriter(filePath, true);

with benefits:

* If the file at filePath already exists, we will append to it (add at its end) instead of overwriting it,
* If the file at filePath does not exist, it is created.

The previous code

StreamWriter sw = new StreamWriter(filePath);

should be used only if we do not care about existing files.

### Many Things Can Go Wrong!

We will not list in detail all the ways things can go wrong with manipulating files, but some examples include:

* memory shortage, for example triggering a OutOfMemoryException from the [StreamReader.ReadLine method](https://learn.microsoft.com/en-us/dotnet/api/system.io.streamreader.readline?view=net-9.0#system-io-streamreader-readline),
* File not being writable (for example, because of access right limitations), triggering an ArgumentException from the [StreamWriter](https://learn.microsoft.com/en-us/dotnet/api/system.io.streamwriter.-ctor?view=net-9.0#system-io-streamwriter-ctor(system-io-stream)) constructor.

In any cases, **accessing files in general should always take place in** try-catch **blocks**. Some simple(r) examples are:

﻿using System;  
using System.IO;  
  
class Program  
{  
 static void Main(string[] args)  
 {  
 Console.WriteLine(  
 @"  
 \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*  
 \* Streamreader constructor exceptions \*  
 \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*"  
 );  
 try  
 {  
 string filePath = null;  
 StreamReader sr = new StreamReader(filePath);  
 }  
 catch (Exception e)  
 {  
 Console.WriteLine(e); // System.ArgumentNullException: Value cannot be null.  
 }  
  
 try  
 {  
 string filePath = "/not/a/proper/path/Test.txt";  
 StreamReader sr = new StreamReader(filePath);  
 }  
 catch (Exception e)  
 {  
 Console.WriteLine(e); // System.IO.DirectoryNotFoundException: Could not find a part of the path "/not/a/proper/path/Test.txt".  
 }  
  
 Console.WriteLine(  
 @"  
 \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*  
 \* Streamwriter constructor exceptions \*  
 \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*"  
 );  
 try  
 {  
 string filePath = null;  
 StreamWriter sr = new StreamWriter(filePath);  
 }  
 catch (Exception e)  
 {  
 Console.WriteLine(e); // System.ArgumentNullException: Value cannot be null.  
 }  
 try  
 {  
 string filePath = "/not/a/proper/path/Test.txt";  
 StreamWriter sr = new StreamWriter(filePath);  
 }  
 catch (Exception e)  
 {  
 Console.WriteLine(e); // System.IO.DirectoryNotFoundException: Could not find a part of the path "/not/a/proper/path/Test.txt".  
 }  
  
 string directoryPath = AppDomain  
 .CurrentDomain  
 .BaseDirectory;  
 }  
}

[*(Download this code)*](https:/princomp.github.io/code/projects/FileExceptions.zip)

Note also that scoping matter, as C# is “pessimistic”: it supposes that everything inside the try portion will fail. For example, one cannot have

// The following would \*not\* compile  
try  
{  
 StreamWriter sw = new StreamWriter(filePath);  
 // …  
}  
catch (Exception ex) { Console.WriteLine(ex); }  
finally  
{  
 sw.Close();  
}

as C# would complain that

The name 'sw' does not exist in the current context

since it assumes that the creation of sw *will* fail.

## In More Details: Streams

The StreamWriter and StreamReader constructors we discussed above can also take System.IO.Stream objects as arguments, and it makes handling of files a bit easier to understand. Indeed, [System.IO.Stream](https://learn.microsoft.com/en-us/dotnet/api/system.io.stream?view=net-9.0) is an abstract class that provides a generic view on sequences of bytes. An object in its class can be a file, a I/O device, a TCP/IP socket, etc.

That means that our StreamWriter and StreamReader objects don’t really see the whole file “all at once”, they process it by loading some of it in a *buffer* (whose size can actually be specified when creating e.g. a [StreamWriter object](https://learn.microsoft.com/en-us/dotnet/api/system.io.streamwriter.-ctor?view=net-9.0#system-io-streamwriter-ctor(system-io-stream-system-text-encoding-system-int32)). Since all the program “see” is [a series of characters containing new line characters](https://learn.microsoft.com/en-us/dotnet/api/system.io.streamreader.readline?view=net-9.0#remarks), as many as its buffer can hold, we cannot for example

* Open the file at an arbitrary line,
* Read the file backward (that is, from the end),
* Search for a particular word,

*unless we write a program to complete this task ourselves*.

Here is an example of a program asking the user to enter a file name, populating it with a random number of random numbers, and then reading it backward:

﻿using System;  
using System.IO;  
  
class Program  
{  
 static void Main(string[] args)  
 {  
 // Setting the directory path to the current  
 // folder, where the binary is located.  
 string directoryPath = AppDomain  
 .CurrentDomain  
 .BaseDirectory;  
 // Asking the user for file name.  
 Console.WriteLine(  
 "Please, enter a file name (hit \"enter\" to use \"test.txt\")."  
 );  
 string fileName = Console.ReadLine();  
 if (fileName == null || fileName == "")  
 fileName = "test.txt";  
 string filePath = Path.Combine(directoryPath, fileName);  
 // Creating a generator for random numbers.  
 Random gen = new Random();  
 int numNum = gen.Next(20, 100);  
 // We will store between 20 and 99 numbers in our file.  
 // We first populate the file with random numbers.  
 try  
 {  
 Console.WriteLine(  
 "Now storing "  
 + numNum  
 + " random numbers into "  
 + filePath  
 + "."  
 );  
 StreamWriter sw = new StreamWriter(filePath);  
 // Further references to sw \*have to be\* on the same try block.  
 for (int i = 0; i < numNum; i++)  
 sw.WriteLine(gen.Next(i + 2));  
 sw.Close();  
 }  
 catch (Exception ex)  
 {  
 Console.WriteLine(ex);  
 }  
  
 // Reading the file and storing its values in a  
 // partially filled array, cf.  
 // https://princomp.github.io/lectures/collections/default\_resizing#partially-filled-arrays  
 int aSize = 5;  
 int cLine = 0;  
 string line;  
 string[] text = new string[aSize];  
 try  
 {  
 StreamReader sr = new StreamReader(filePath);  
 line = sr.ReadLine();  
 while (line != null)  
 {  
 // Uncomment if you would like to test / see the file displayed forward first.  
 // Console.WriteLine(line);  
  
 if (cLine + 1 > aSize)  
 {  
 aSize \*= 2;  
 Array.Resize(ref text, aSize);  
 }  
 text[cLine] = line;  
 cLine++;  
 line = sr.ReadLine();  
 }  
 sr.Close();  
  
 Console.WriteLine(  
 "Displaying the file starting from the end:"  
 );  
 for (int i = cLine - 1; i >= 0; i--)  
 {  
 Console.WriteLine(text[i]);  
 }  
 }  
 catch (Exception ex)  
 {  
 Console.WriteLine(ex);  
 }  
 }  
}

[*(Download this code)*](https:/princomp.github.io/code/projects/FileBackward.zip)

1. Although that may sound curious, we believe it is important to remind you of the fact that they can only *help* you understanding, but that you have to do your part! [↑](#footnote-ref-1)
2. That’s a job really well taken care of by the [Academic Success Center](https://www.augusta.edu/academicsuccess/)! [↑](#footnote-ref-2)
3. Unless this class is fully online, of course. [↑](#footnote-ref-3)
4. That will be studied in the course of your study if you continue as a CS major. [↑](#footnote-ref-4)
5. We use the notation […] to denote what “should” be there, but this is just a place holder: you are not supposed to *actually* have the braces in the code. [↑](#footnote-ref-5)
6. Well, if there are no in-line comments in it. Can you figure out why? [↑](#footnote-ref-6)
7. At this point, you may wonder “why don’t we always use the most precise datatype instead of using imprecise ones?”. There are three dimensions to consider to answer this question: first, using decimal takes more memory, hence more time, than the other numerical datatypes. Second, they are a bit more cumbersome to manipulate, as we will see later on. Last, you generally don’t need to be *that* precise: for example, it would not make sense to use a floating-point number to account for human beings or other indivisible units. Even decimal may be an overkill for floating-point values sometimes: for instance, the [NASA uses 3.141592653589793 as an approximation of pi](https://www.jpl.nasa.gov/edu/news/2016/3/16/how-many-decimals-of-pi-do-we-really-need/) for their calculations. A [double can hold such a value](https://learn.microsoft.com/en-us/dotnet/api/system.math.pi?view=net-8.0), so there is no need to be more precise. [↑](#footnote-ref-7)
8. We use “bike” to refer to both bicycles and motorcycles. [↑](#footnote-ref-8)
9. Technically, a “rectangular pyramid”, if we require the pyramid to have a rectangle as its base. [↑](#footnote-ref-9)
10. A method that is not itself overriding cannot use the sealed keyword: [it should “simply” not being declared abstract](https://stackoverflow.com/questions/13858384/sealed-keyword-in-association-with-override/13858411#13858411). [↑](#footnote-ref-10)
11. Which should have the same signature *and* return type. [↑](#footnote-ref-11)
12. Note that, this time, since our code below does **not** override the methods and properties, there really is no need to repeat them the derived classes. [↑](#footnote-ref-12)
13. Except that the fork bomb calls itself *twice*, and in parallel. [↑](#footnote-ref-13)
14. Usually, all the elements of an array have the same type, but an array can store elements of different types if object is its type, since any element is actually of type object. [↑](#footnote-ref-14)
15. That is, unless the program crashes or loops forever. [↑](#footnote-ref-15)