Module 1: Types and Expressions

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Thanks to Alan Waldman
for comments that improved these slides

Prepared for 2u
Semester Online

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1.0 Introduction

- **What is a type?**
  - A classification of items in the world based on
    - The kinds of things an item can do
    - The
    - integers, real numbers, character strings, ...

- **As types, consider integers and real numbers**
  - **integer**
    - Useful for counting
    - Number of playing cards in a deck
  - **Real number**
    - Can include fractional values
    - Temperature readings and averages, interest rates
    - On the computer, we can only approximate real numbers

- **Data types in computer science**
  - Represent values of interest
  - Allow operations that make sense

- **Built in data types (in this module)**
  - For representing integers, interest rates, names, addresses, facts

- **Later, we design our own types**
  - Bank account, hockey player, song

- **The best choice of data type is not always obvious**
  - Should you use an integer or a real number?
  - You might start with one, and change your mind later
    - Height – might be integer number of centimeters
    - But if we're measuring something small, fractional values may be needed

- **There are rarely right or wrong choices**
  - But a choice will have its advantages and disadvantages
  - Picking a suitable data type is an engineering process and is based on currently understood constraints and best planning for the future. The future can at times seem uncertain.
  - Example: Y2K
1.1 Our first data type: int

- The \texttt{int} data type allows us to represent integer-valued items

- The above are 0 or positive, but negative values may be of interest as well
  - How many days until your 21\textsuperscript{st} birthday?

- The week before, 7
- The week after, -7

- How has the class size changed since yesterday?
  - +5 students were added
  - -3 students dropped
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• The int data type allows us to represent integer-valued items
  – How many students are in this class?
  – How many exams will be given?
  – How many words are in this sentence?

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1.1 Our first data type: int

- Most programming languages have practical limits on the values represented by a simple data type
  - Minimum value: -2,147,483,648
  - Maximum value: 2,147,483,647
- These seem just fine for the quantities suggested thus far
  - But how about the distance from Earth to Sun?
    - In meters: 149,597,870,700
      - Too big!
- We can represent values outside of the range of an int using techniques we learn later.
- For now, we consider an int sufficient.
- There are things we cannot represent conveniently with an int
  - Your name (need the alphabet, not just 0—9)
  - Your height in meters (need fractions)
  - Whether you are vegetarian or not
- We will see other data types soon that help us with those...
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• How do we represent a concept using the int data type? We do this by specifying:
  – The type of the concept (int)
  – A name for the concept (numStudents, numExams, etc.)
  – A value for the concept
    • This value can change later, but it is important to have an initial value for the concept.

  int numStudents = 390;
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• There are conventions about how to pick variable names:
  – The first letter of the first word in a name begins with a lower-case letter
  – Each subsequent word begins with an upper-case letter
  – There are no spaces (blanks) in a variable name
    • This value can change later, but it is important to have an initial value for the concept.

• The name should be meaningful, clear, and relevant to the concept
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int numStudents = 390;
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- Any valid expression can appear on the right-hand side
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```
int numStudents = 390;
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- An assignment statement is evaluated as follows
  - The value of the right-hand side is computed (390 in this case)
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int numStudents = 390;
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• An assignment statement is evaluated as follows
  – The value of the right-hand side is computed (390 in this case)
  – The result is stored at the name declared on the left-hand side
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    int numStudents = 390;

    int numWaitListed = 20;
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        int numStudents = 390;
        int numWaitListed = 20;

• The computer executes your statements in sequence
  – One after the other
  – From the top, reading down
1.1 Our first data type: int

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```java
int numStudents = 390;
int numWaitListed = 20;
int totalStudents = numStudents + numWaitListed;
```

```
390 + 20 = 410
```
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int numStudents = 390;
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```
int numStudents = 390;
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numStudents = numStudents + 5;
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Because we are assigning a previously-declared variable numStudents a new value, its type has already been declared as int, and we are not allowed to declare its type ever again.
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```
  390
    +
     5
    →
      395
```
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```java
int numStudents = 390;
int numWaitListed = 20;
int totalStudents = numStudents + numWaitListed;
```

numStudents = numStudents + 5;

- Remember: we do not re-declare numStudents
  - It is already known to be an int
  - The new value simply replaces the old value
1.1 Our first data type: int

- The computer executes your statements in sequence
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  - From the top, reading down

```
int numStudents = 390;
int numWaitListed = 20;
int totalStudents = numStudents + numWaitListed;

numStudents = numStudents + 5;
```

- Other values are *not* automatically updated
  - They have only been assigned their initial value
  - Code executes from the top, reading down
### 1.1 Our first data type: int

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int numStudents = 390;

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int totalStudents = numStudents + numWaitListed;

numStudents = numStudents + 5;

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1.1b Exercise

• Video intro
  – Important to try things out in small doses
  – Story
    • Alice has 7 carrots
    • Bob has 3 more than Alice
    • Charles has 4 times as many as Alice
    • Also, Charles stole all of Bob's carrots
    • Diane has twice as many as Charles

• Question card: Translate the story to code
  – Print out how many Diane has at the end
    • System.out.println(dianeCarrots);

• Response: go over my solution
1.1c Now get input from the user

• Student asks question about how to make Alice's carrots a value input by the user
  – Much more on this later
  – But for now we use the ArgsProcessor stuff
• Show what happens when we try to use it
  – import the right thing with eclipse's help
• Meaningful prompting messages
• Run it a few times
1.2 Operations on int types

- Most operations work as expected
  - + plus
  - - minus
  - * times

- One operation usually surprises students and experienced programmers alike
  - Division using the / operator
  - Returns an int, so no fractional values are allowed
  - The value returned is as if the digits past the decimal point were dropped

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- One operation usually surprises students and experienced programmers alike
  - Division using the / operator
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  - The value returned is as if the digits past the decimal point were dropped
  - We are not allowed to divide by 0

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</tr>
<tr>
<td>7 / 0</td>
<td>Error !</td>
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1.2 Operations on int types

• The \% operator computes the remainder after division

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Why is this useful?
1.2 Operations on int types

• The % operator computes the remainder after division

• Examples:
  – Convert a large number of pennies into dollars and cents

```c
int pennies = 789321;
```

<table>
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1.2 Operations on int types

- The % operator computes the remainder after division

- Examples:
  - Convert a large number of pennies into dollars and cents

```java
int pennies = 789321;
int dollars = pennies / 100;
```

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1.2 Operations on int types

- The % operator computes the remainder after division
- Examples:
  - Convert a large number of pennies into dollars and cents

```plaintext
int pennies = 789321;
int dollars = pennies / 100;
int cents = pennies % 100;
```

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<tr>
<td>cents</td>
<td>21</td>
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End of Oyster
1.3 Exercise

• **Video intro**
  
  – We see how to take a number of pennies and compute the dollars and cents contained therein
  
  – First we'll write code for that much and make sure it works.
  
  – Then we will incrementally improve the code
    
    • Allow quarters in change
    
    • Allow nickels and dimes too
1.3 Exercise

• Question card
  – **Write code that gives change as follows:**
    • Prompt the user for a number of pennies
      – Call this value initialPennies
    • Compute d as the number of dollars contained therein
      – Let’s assume the user trades in the appropriate number of pennies for the d dollars
    • Compute penniesLeftAfterDollars as the number of pennies that remain
    • Print out the dollars and cents that are contained in the initialPennies
  – **Try out your code and make sure that it works**
1.3 Exercise

• Question card
  – Now improve your code so that quarters can be given as well
    • Assume penniesLeftAfterDollars remain after dollars are given
    • How many quarters could be substituted for that many pennies? Call this value $q$ and print it out as well as the pennies left over after dollars and quarters are exchanged

• Example: 798 pennies
  – 7 dollars, leaving 98 penniesAfterCollars
  – $q=3$ quarters in 98 pennies
  – 23 pennies left over
1.3 Exercise

• Question card
  – Now improve your code so that change can be made
    • dollars
    • quarters
    • dimes
    • nickels
    • pennies left over
1.3 Exercise

• Example
  – 798 pennies initially
  – Should get
    • 7 dollars, leaving 98 cents
    • 3 quarters, leaving $98 - 75 = 98 \% 25 = 23$ cents
    • 2 dimes, leaving 3 cents
    • 0 nickels
    • 3 pennies
1.3 Exercise

• Video response
  – Goes over a correct solution line by line using the example from the setup
  – How would we verify that the answer we produced was correct?
    • $d \times 100 \ + \ q \times 25 \ + \ d \times 10 \ + \ n \times 5 \ + \ p$ should equal initialPennies
Roundtable

- Conversation about implementation of math on computers
  - If we have the largest integer value and add 1 to it, what happens?
    - Show this with screenflow movie

- We see computers of all sizes
  - Desktops, laptops, cell phones, smart watches
  - The basic hardware mechanisms of those computers can perform arithmetic differently
    - Largest and smallest values

- Java requires all computers to perform arithmetic Java's way
  - Because of Internet applets
  - A Java program runs the same way anywhere
  - Widespread portability and software reliability
1.4 Building Bigger Expressions

• We can combine smaller expressions into bigger
  – Using operators between smaller expressions
  – Using parentheses
    • To direct the order of evaluation
    • To improve the clarity of the expression

• My Dear Aunt Sally
  – Multiplication and Division have higher precedence
  – Addition and Subtraction have lower precedence
  – Evaluation is otherwise left-to-right
  – Parenthesized expressions have highest precedence
## 1.4 Building Bigger Expressions

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- To understand how an expression is computed, we draw its evaluation tree.
- Evaluation proceeds from the leaves of the tree toward its root.
- A node can be computed only when the values from all of its children are available.

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• To understand how an expression is computed, we draw its evaluation tree
• Evaluation proceeds from the leaves of the tree toward its root
• A node can be computed only when the values from all of its children are available
• Expression is complete, and value is stored

```c
int val = (2 + 3) / 2;
```
1.4 Building Bigger Expressions

4 \quad - \quad 3 \quad - \quad 2 \quad - \quad 1

4 \quad - \quad (3 \quad - \quad (2 \quad - \quad 1))
1.4 Building Bigger Expressions

• These large and complicated expressions are truly pedagogical examples

• We write programs not only for the computer
  – But for other humans to understand

• The computer has no problem with large, complicated expressions
  – But we humans do!

• Better to write simpler, easier-to-read expressions
  – If it takes you time to understand what you wrote, then what you write is too complicated
  – A good test is to show a friend your code and get critical feedback about its quality and readability
1.5 The `double` data type

- The `int` data type allows us to represent integer-valued items
  - How many students are in this class?
  - How many exams will be given?
  - How many words are in this sentence?

- We sometimes need value beyond the decimal point
  - The average age of students in this class
  - The probability of "heads" on a coin flip

- We sometimes need really large or small values
  - $6.0221413 \times 10^{23}$ (Avogadro's number)
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1.5 The double data type

• The syntax is similar
  – The type is different (double)
    • This is an unfortunate choice of name for a type
      – It refers to the amount of space used on a computer to represent the type.
    • We should think of it as a type that represents rational or real numbers

```c
double secsPerMeter = .000000003;
```
1.5 The `double` data type

- The syntax is similar
  - The type is different (`double`)
  - We can use scientific notation
    - The E character represents “times 10 to the”
    - You can also specify the E as lower-case e

```c
double secsPerMeter = 3E-9;
```
1.5 The double data type

- Most operations work as expected
  - + plus
  - - minus
  - * times

- As with int, division has some quirks for double
  - You can divide by 0
    - And get either Infinity or NaN (Not a Number)

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- There are other surprises
  - The data type is inexact for some values
  - For nonrationals there is nothing we can do about this
    - How would you represent “pi” exactly?
  - For rationals, we can design a better data type
    - But the fastest arithmetic on the computer is approximate in terms of values, as shown below

- All of this is governed by an accepted standard
  - IEEE 754

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- Languages provide math libraries with useful functions and values
  - **Maximum and minimum**
    - `Math.max(1.3, 34)`
    - `Math.min(-5, 23)`
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  - **Constants**
    - `Math.PI` – closer to the actual value of $\pi$ than any other `double`
    - `Math.E` – closer to the actual value of $e$ than any other `double`
- **Many, many more.** See [this link](#)
Roundtable

• Randomness
  – Run the random number generator and observe some of its outputs
  – Compute the average of 10 such numbers

• Pseudo-random
  – What does this mean?
1.6 Mixed-type Expressions

• We can combine types in expressions where this makes sense
  – Here we look at int and double types
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  – The result is usually of the more general type
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- We can combine types in expressions where this makes sense
  - Here we look at int and double types
- If two types participate in an expression
  - The result is usually of the more general type
- The double type is more general than the int type
  - We can represent any int as a double
    - For example, 3 becomes 3.0
  - But the converse is not true
    - No way to represent 0.5 as an int
1.6 Mixed-type Expressions

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</tr>
<tr>
<td><code>int area = 3.4;</code></td>
<td>Not allowed</td>
</tr>
<tr>
<td><code>int area = (int) 3.4;</code></td>
<td>Allowed, but we lose the data after the decimal point. The conversion requires the <em>explicit cast</em>, shown in the red box. Casts have very high precedence</td>
</tr>
<tr>
<td><code>int avg = (2 + 3) / 2;</code></td>
<td>Allowed, but the result is <em>not</em> 2.5! The result is computed in integer arithmetic, so the value assigned to <code>avg</code> is 2</td>
</tr>
<tr>
<td><code>double avg = (2 + 3) / 2;</code></td>
<td>The right-hand side is computed first, resulting in 2, and that value is then stored in the variable, which results in the value 2.0 for <code>avg</code></td>
</tr>
</tbody>
</table>
1.6 Mixed-type Expressions

• To understand how an expression is computed, we can draw its evaluation tree

```java
double avg = (double) (2 + 3) / 2;
```

5
1.6 Mixed-type Expressions

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![Evaluation Tree Diagram]

5.0
1.6 Mixed-type Expressions

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double avg = (double) (2 + 3) / 2;
```

```
   double avg = (double) (2 + 3) / 2;
      /|
     / |
    /  |
   5.0 |
   /   |
  /    |
 5.0   |
  /     |
 /      |
2.5    |
```
1.6 Mixed-type Expressions

- To understand how an expression is computed, we can draw its *evaluation tree*

```java
double avg = (double) (2 + 3) / 2;
```

![Evaluation Tree Diagram]

- Result: `avg = 2.5`
1.6 Mixed-type Expressions

• What value results from the following expression?

\[(\text{double}) \frac{1}{2} + \frac{2}{3} + \frac{3}{4}\]
1.6 Mixed-type Expressions

• What value results from the following expression?

\[
\text{(double) } 1 / 2 + 2 / 3 + 3 / 4
\]

1.0
1.6 Mixed-type Expressions

• What value results from the following expression?

\[(\text{double}) \frac{1}{2} + \frac{2}{3} + \frac{3}{4}\]

\[= 0.5 + 0.666... + 0.75\]

\[= 1.916...\]
1.6 Mixed-type Expressions

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1.6 Mixed-type Expressions

- What value results from the following expression?

```
(d) (1 / 2) + (2 / 3) + (3 / 4)
```

```
1.0 + 0.6667 + 0.75 = 2.4167
```
1.7 Strings

- A useful data type for representing text
- **String literals** are specified using double quotes
  - "Hello"
  - "This is a string."
  - "" (an empty string)
1.7 Strings

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  – "Hello"
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  – The symbol means *concatenation*
  – It is overloaded from arithmetic for int and double types
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<thead>
<tr>
<th>Example</th>
<th>Result, if printed</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Hello&quot; + &quot;there&quot;</td>
<td>Hello there</td>
</tr>
<tr>
<td>&quot;Hello &quot; + &quot;there&quot;</td>
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</tr>
<tr>
<td>&quot;&quot; + &quot;&quot; + &quot;&quot;</td>
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1.7 Strings

• Declarations and assignments are the same as before.

```java
String s1 = "ei";
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• Declarations and assignments are the same as before. Use of the capital S is important!

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String s1 = "ei";
String s2 = s1 + s1;
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1.7 Strings

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String s1 = "ei";

String s2 = s1 + s1;

String s3 = s2 + "o";
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### 1.7 Strings

- Conversion from other expression types to String produces the text form of their values.
- Given a String \( s \), \( s.length() \) returns the length of the string in characters.

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<td>String msg = pounds + &quot; ft&quot;;</td>
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<td>int length = msg.length()</td>
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<td>this case, 6 is returned.</td>
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End of Oyster
1.8 The boolean data type

• Useful for representing two-valued concepts
1.8 The boolean data type

- Useful for representing two-valued concepts
  - True vs. false
  - Heads vs. tails
  - Open vs. closed
1.8 The boolean data type

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  - True vs. false
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  - But lower case $b$ is important
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  - True vs. false
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  - Open vs. closed

- Named after George Bool
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  - But lower case b is important

- Only two constants (lower case is important)
  - true
  - false
1.8 The boolean data type

• Mathematical operators work as expected, though some are spelled strangely
  – == for equality
  – != for inequality
  – <= for ≤, etc.

<table>
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The usual rules of conversion apply here. The int 7 is converted to the double 7.0 and the comparison with 3.5 is then made.
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1.8 The boolean data type

• Logical operators are also available.
  – Complement
    • !p is true if p is false
    • !p is false if p is true
1.8 The boolean data type

• Logical operators are also available.
  – Complement
    • !p is true if p is false
    • !p is false if p is true
  – And
    • p && q is true if both p and q have the value true
    • Works as expected for English meaning of and
1.8 The boolean data type

• Logical operators are also available.
  – Complement
    • \(!p\) is true if \(p\) is false
    • \(!p\) is false if \(p\) is true
  – And
    • \(p \&\& q\) is true if *both* \(p\) and \(q\) have the value *true*
    • Works as expected for English meaning of *and*
  – Or
    • \(p \|\| q\) is true if *either* \(p\) or \(q\) is true, or if *both* \(p\) and \(q\) are true
    • \(p \|\| q\) is false only if \(p\) is false and \(q\) is false
1.8 The boolean data type

• Logical operators are also available.
  – Complement
    • \( \neg p \) is true if \( p \) is false
    • \( \neg p \) is false if \( p \) is true
  – And
    • \( p \land q \) is true if both \( p \) and \( q \) have the value true
    • Works as expected for English meaning of *and*
  – Or
    • \( p \lor q \) is true if either \( p \) or \( q \) is true, or if both \( p \) and \( q \) are true
    • \( p \lor q \) is false only if \( p \) is false and \( q \) is false
    • This is different from the way we use *or* in English
      – I am going to the store or I am going to a movie
      – Means one or the other, but not both
1.8 The boolean data type

- Examples

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1.9 Conclusion

- **What is a type?**
  - A classification of items in the world based on
    - The kinds of things an item can do
    - The integers, real numbers, character strings, true/false values
- **Types are also defined by the operations associated with them**
- **Data types in computer science**
  - Represent values of interest
  - Allow operations that make sense
- **Built in data types (in this module)**
  - For representing integers, interest rates, names, addresses, facts
- **Later, we design our own types**
  - Bank account, hockey player, song
- **The best choice of data type is not always obvious**
  - You may start with one and change your mind later
- **There are rarely right or wrong choices**
  - But a choice will have its advantages and disadvantages
  - Picking a suitable data type is an engineering process and is based on currently understood constraints and best planning for the future. The future can at times seem uncertain.