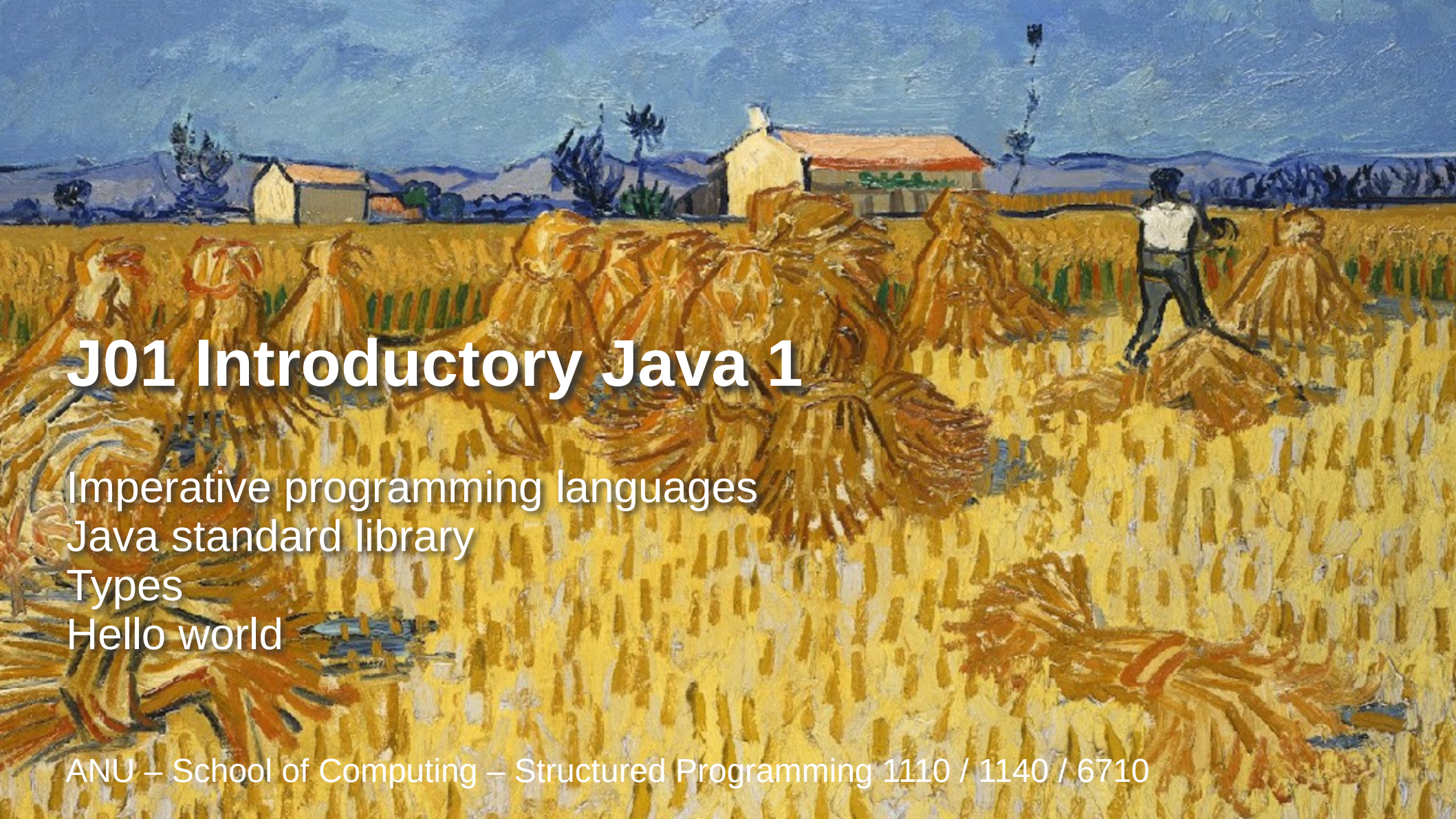

J01 Introductory Java 1

Imperative programming languages
Java standard library
Types
Hello world


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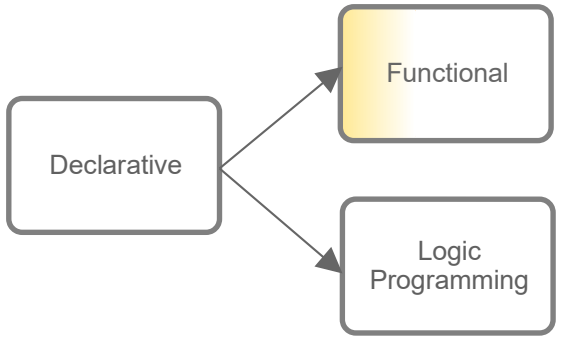
Why Java?

- Learn multiple programming paradigms
- Important example of:
  - Object-oriented programming
  - Large scale programming
  - Programming with a rich standard library

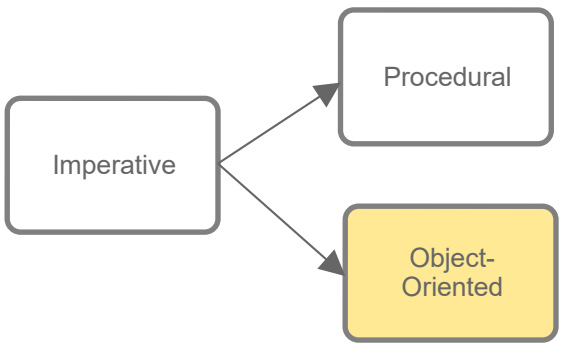
Programming Paradigms

Declarative programming describes the desired result without explicitly listing steps required to achieve that goal.



Pure functional programming only transforms state using functions without side effects.

Imperative programming describes computation in terms of a series of commands that transform state.



Procedural programming uses procedures to transform data structures

Object-oriented programming tightly groups the procedures and data structures together into “objects”

Structured Programming

Another paradigm that imposes **a logical structure to code** making it easier to understand and less error prone.

- Structured control flow (e.g., no GOTOs)
- Callable units (functions / methods / procedures)
- Block structure and scoping

“Structured program theorem” gives the building blocks:

- Sequence
- Selection
- Iteration

Type Systems

`00110001 ?`

$2^5+2^4+2^0 = 49$?

`R of RGB value ?`

`ASCII Char ‘1’ ?`

`X86 Opcode XOR ?`

The type of a unit of data determines the possible values that data may take on, and the ways it may be operated on.

Ensuring the constraints on types are obeyed is *type checking*:

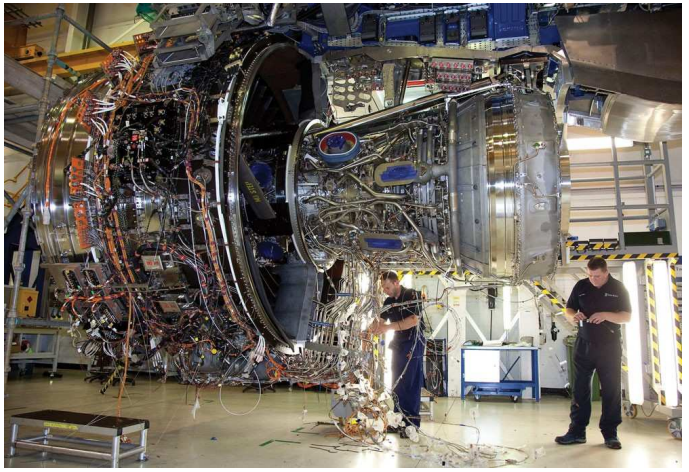
- **Static** type checking: done at **compile time**
  - Java / Haskell / C
- **Dynamic** type checking: done at **runtime**
  - Python / Javascript

Syntax and Semantics

- **Syntax**: the ways characters can be structured to create a valid program in the given language
  - 3 + 5: a valid expression involving a number, a binary operator, and then another number
- **Semantics** (meaning / behaviour): what that syntax represents / how the program will behave
  - 3 + 5: evaluates to a new integer (8) that is the sum of the two integer operands (informally)

Abstraction

- Controlling **complexity**.
- Forming **modules** / components that hide unimportant details from the user and provide an intuitive **interface** to other components.
- Enabling more of the system to fit in our limited fleshy brains at once, without losing the key interactions.
- **Generalising** capability.
- Critical in all languages / paradigms.



Rolls Royce Trent XWB for the A350. Photo: AINonline

The Oracle Java Tutorials

This course follows the structure of the Oracle Java Tutorials for the basic introduction to Java.

The tutorials are subject to Oracle's 'Java Tutorial Copyright and License' (Berkeley license).

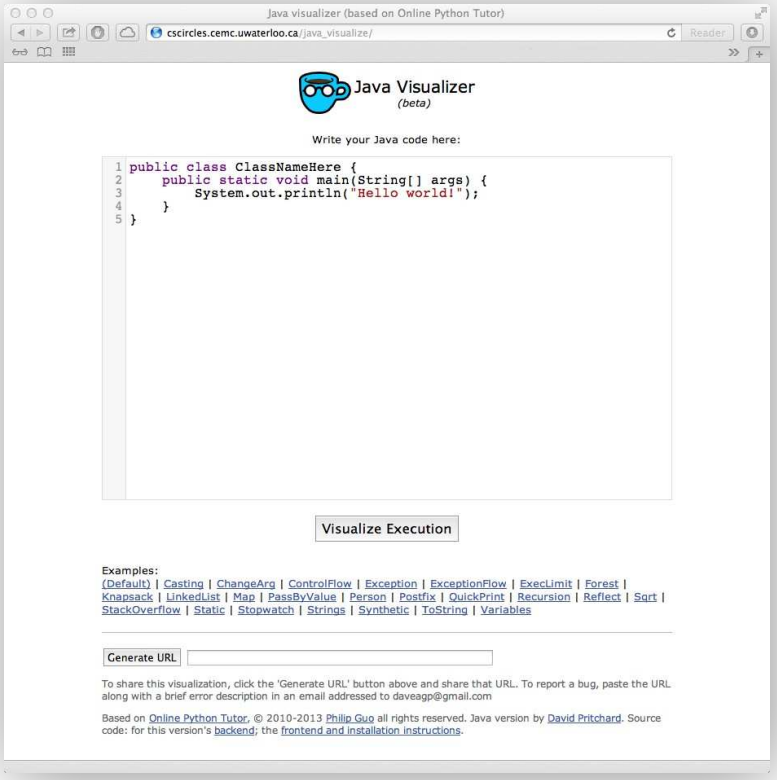
We will move very fast for the first few weeks. You should use the tutorials to ensure that you rapidly become proficient in the basics of Java.

The Java Standard Library

- The Java language is augmented with a large standard library (.NET does the same for C#)
  - IO (accessing files, network, etc.)
  - Graphics
  - Standard data structures
  - Much more
- Using and understanding the standard library is part of learning a major language like Java or C#.
- Rich standard libraries are a key software engineering tool.

The Waterloo Java Visualizer

Type in simple Java programs and watch step-by-step execution. A great way to enhance your understanding of a new language.



J02 Introductory Java 2

Types
Objects
Classes
Interfaces
Inheritance

ANU – School of Computing – Structured Programming 1110 / 1140 / 6710

Objects

Objects combine state and behaviour

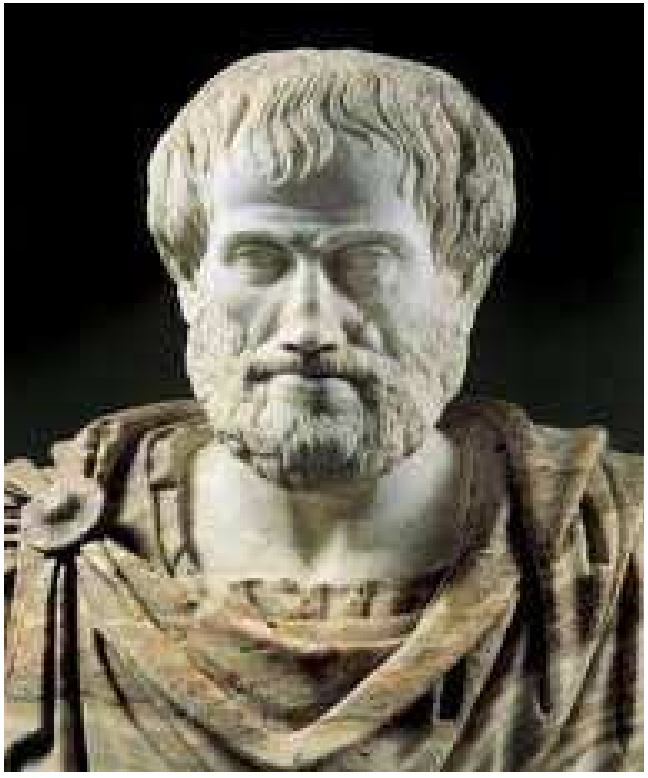
- **State**: fields (data)
- **Behaviour**: methods (code)

Example: Bicycle

- **State**: current direction, speed, cadence, gear
- **Behaviour**: turn, change cadence, brake, change gear

Classes

Aristotle 384-322 BC



“Blood-bearing animals””:

- Four-footed animals with live young,
- Birds,
- Egg-laying four-footed animals,
- Whales,
- Fishes

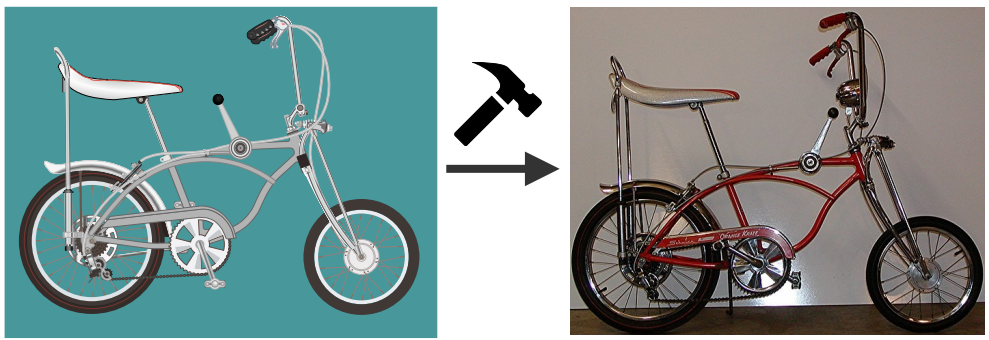
Classes

A class is a blueprint or ‘type’ for an object

- **Class**: blueprint / definition used for multiple instances
- **Instance**: one instantiation of a class (aka object)

Example:

- **Class**: Schwinn Sting-Ray
- **Instance**: your bike



Java Interfaces

An `interface` is a group of methods without implementations (methods define behaviour)

Example: an `interface` `MovableThing` might include:

- `brake()`
- `speedup()`

Any class that *`implements`* `MovableThing` must include definitions of these methods.

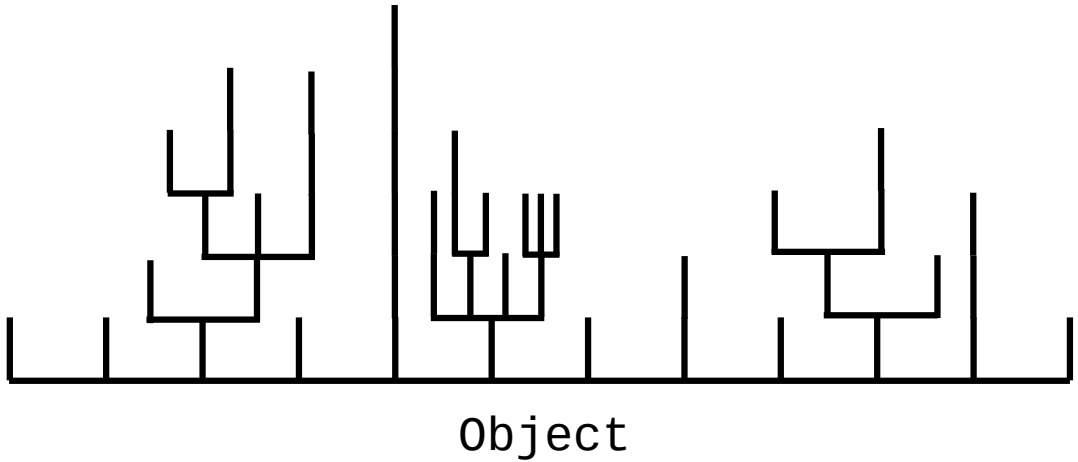
Inheritance

Classes may form a hierarchy

- sub-class `extends` a super-class
- child-class `extends` a parent-class

Example:

```
SchwinnStingRay extends
WheelieBike extends
UprightBike extends
Bike extends
Object (Root of all Java Classes)
```



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J03 Introductory Java 3

Naming
Literals
Primitives

Java Packages

Which Mary?

Mary Queen of Scots

‘Queen of Scots’ provides a namespace within which ‘Mary’ is well defined. In Java a `package` provides a namespace.

Java Modules

- A module is a named group of packages and related resources
- Strong encapsulation
- Explicit dependencies

```
module java.sql {
 requires transitive java.logging;
 requires transitive java.transaction.xa;
 requires transitive java.xml;

 exports java.sql;
 exports javax.sql;

 uses java.sql.Driver;
}
```

Java Variables

- **Instance** (non-static fields, object-local)
  - Each object has its own version (instance) of the field
- **Class** (static fields, global)
  - Exactly one version of the field exists
- **Local**
  - Temporary state, limited to execution scope of code
- **Parameters**
  - Temporary state, limited to execution scope, passed from one method to another

Java Naming

- Java names are case-sensitive
  - Whitespace not permitted
  - $, _ to be avoided
  - Java keywords and reserved words cannot be used
- Capitalization conventions
  - Class names start with capital letters (`Bike`)
  - Variable names start with lower case, and use upper case for subsequent words (`currentGear`)
  - Constant names use all caps and underscores (`MAX_GEAR_RATIO`)

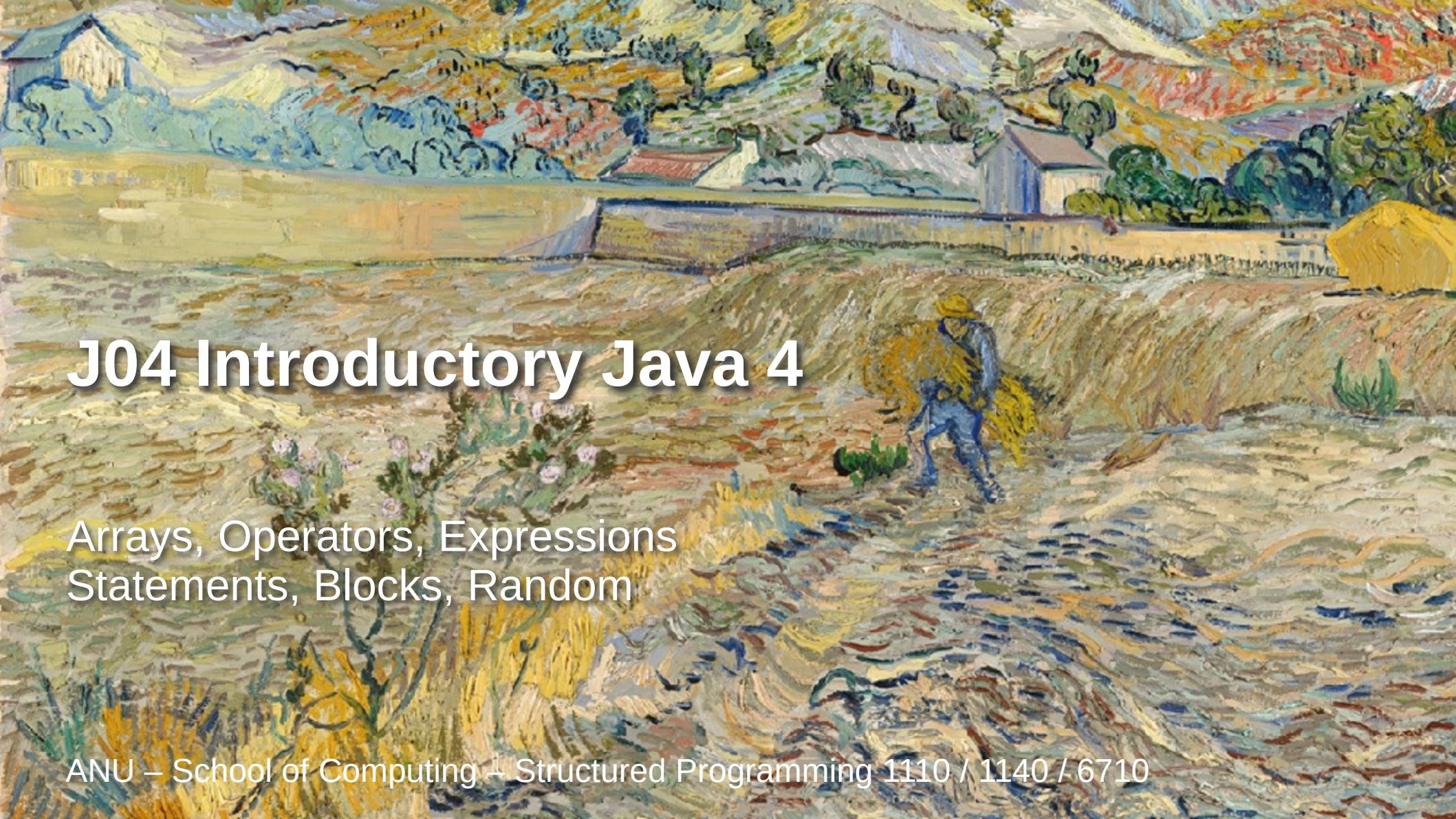
Java's Primitive Data Types

In addition to objects, Java has 8 special, built-in 'primitive' data types.

type	Description	Range	Default
byte	8-bit signed 2's complement integer	-128 - 127	0
short	16-bit signed 2's complement integer	-32768 - 32767	0
int	32-bit signed 2's complement integer	-2^{31} - $2^{31}-1$	0
long	64-bit signed 2's complement integer	-2^{63} - $2^{63}-1$	0L
float	single precision 32-bit IEEE 754 floating point number		0.0f
double	double precision 64-bit IEEE 754 floating point number		0.0d
boolean	logically just a single bit: true *or* false	**true**, **false**	**false**
char	16-bit Unicode character	0 - 65535	0

Java Literals

- When a numerical value (e.g. ‘1’) appears, the compiler normally knows exactly what it means.
- Special cases:
  - An integer value is a long if it ends with ‘l’ or ‘L’
  - The prefix 0x indicates hexadecimal, 0b is binary, 0 octal:
    - `0x30     // 48 expressed in hex`
    - `0b110000 // 48 expressed in binary`
    - `060      // 48 expressed in octal`
  - An ‘f’ indicates a float, while ‘d’ indicates double.
  - Underscores may be used to break up numbers:
    - `long creditCardNumber = 1234_5678_9012_3456L;`



J04 Introductory Java 4

Arrays, Operators, Expressions
Statements, Blocks, Random

Java Arrays

Arrays hold a fixed number of values of a given type (or sub-type) that can be accessed by an index.

- Declaring:
```
int[] values;
```
- Initializing:
```
values = new int[8]; // 8 element array, all zeros
values = new int[]{1, 2, 3, 4}; // with specific values
```
- Accessing:
```
int x = values[3];   // the 4th element
```
- Copying:
```
System.arraycopy(x, 0, y, 0, 8);
```

Java Operators

- Assignment
  `=`
- Arithmetic
  `+ - * / %  += +- *= /= %=`
- Unary
  `+ - ++ -- !`
- Equality, relational, conditional and instanceof
  `== != > >= < <= && || instanceof`
- Bitwise
  `~ & ^ | << >> >>>`

Expressions

- A construct that evaluates to a **single value**.
- Made up of
  - variables
  - operators
  - method invocations
- Compound expressions follow precedence rules
  - Use parentheses (clarity, disambiguation)

Statements

- A complete unit of execution.
- **Expression** statements (expressions made into statements by terminating with ‘;’):
  - Assignment expressions
  - Use of ++ or --
  - Method invocations
  - Object creation expressions
- **Declaration** statements
- **Control flow** statements

Blocks

- Zero or more statements between balanced braces (‘{’ and ‘}’)
- Can be used anywhere a single statement can

The Random Class

The Random class provides a pseudo-random number generator:

```
Random rand = new Random();
```

You can optionally provide a seed (for determinism):

```
Random rand = new Random(12345);
```

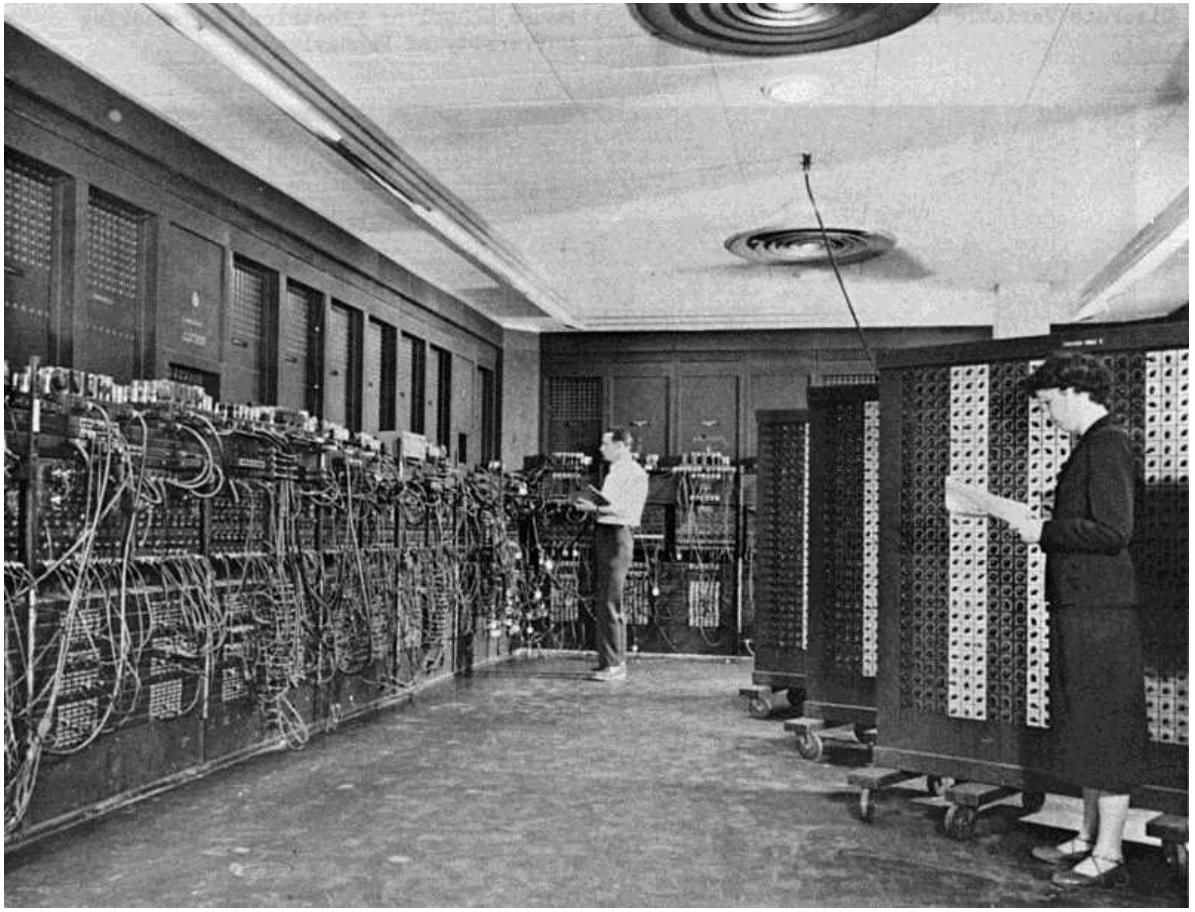
You can then generate random numbers of different types:

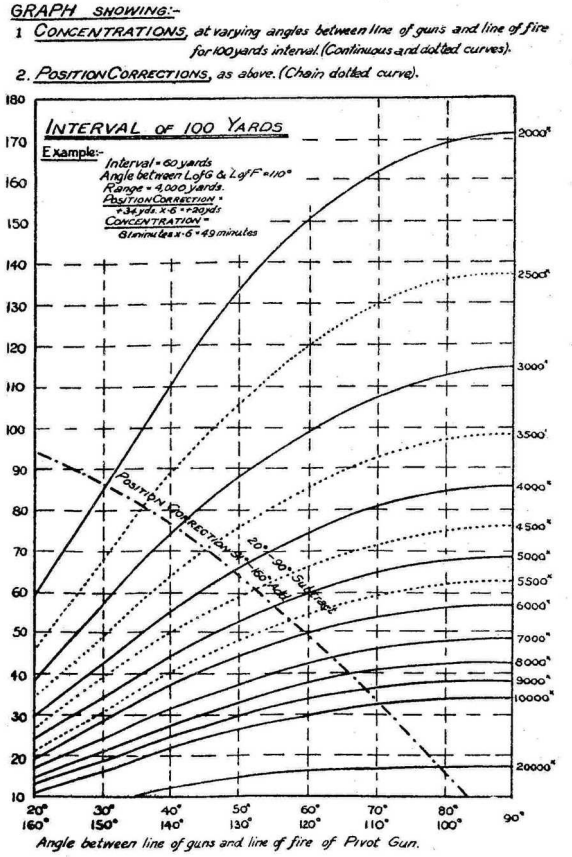
```
int i = rand.nextInt(10); // number in 0-9
```

J05 Control Flow 1

Control flow
if-then-else
switch

Women workers (‘computers’) in a calculation “factory,” 1930s. Courtesy of the Library of Congress.





Calculating a trajectory could take up to 40 hours using a desk-top calculator. The same problem took 30 minutes or so on the Moore School's differential analyzer. But the School had only one such machine, and since each firing table involved hundreds of trajectories it might still take the better part of a month to complete just one table. [Winegrad & Akera 1996]

Control Flow

Control flow statements allow the execution of the program to deviate from a strictly sequential execution of statements (‘selection’).

Structured programming: sequence, **selection**, iteration.

`if`-then & `if`-then-`else` statements

- The `if`-then construct conditionally executes a block of code.
- The `if`-then-`else` construct conditionally executes one of two blocks of code.

The *old* `switch` statement

- The `switch` statement selects one path among many.
- Execution jumps to the first matching `case`.
- Execution continues to the end of the `switch` unless a `break` statement is issued.

The *new* `switch` expression

- The `switch` expression selects one value among many.
- Execution jumps to the first matching `case`.
- The value of the expression is given by the `yield` operator in the matching case.

J06 Control Flow 2

Control flow
while and do-while
for
break, continue, return

The `while` and `do-while` statements

- The `while` statement continuously executes a block while a condition is true.
- The `do-while` construct evaluates the condition at the end of the block rather than at the start.

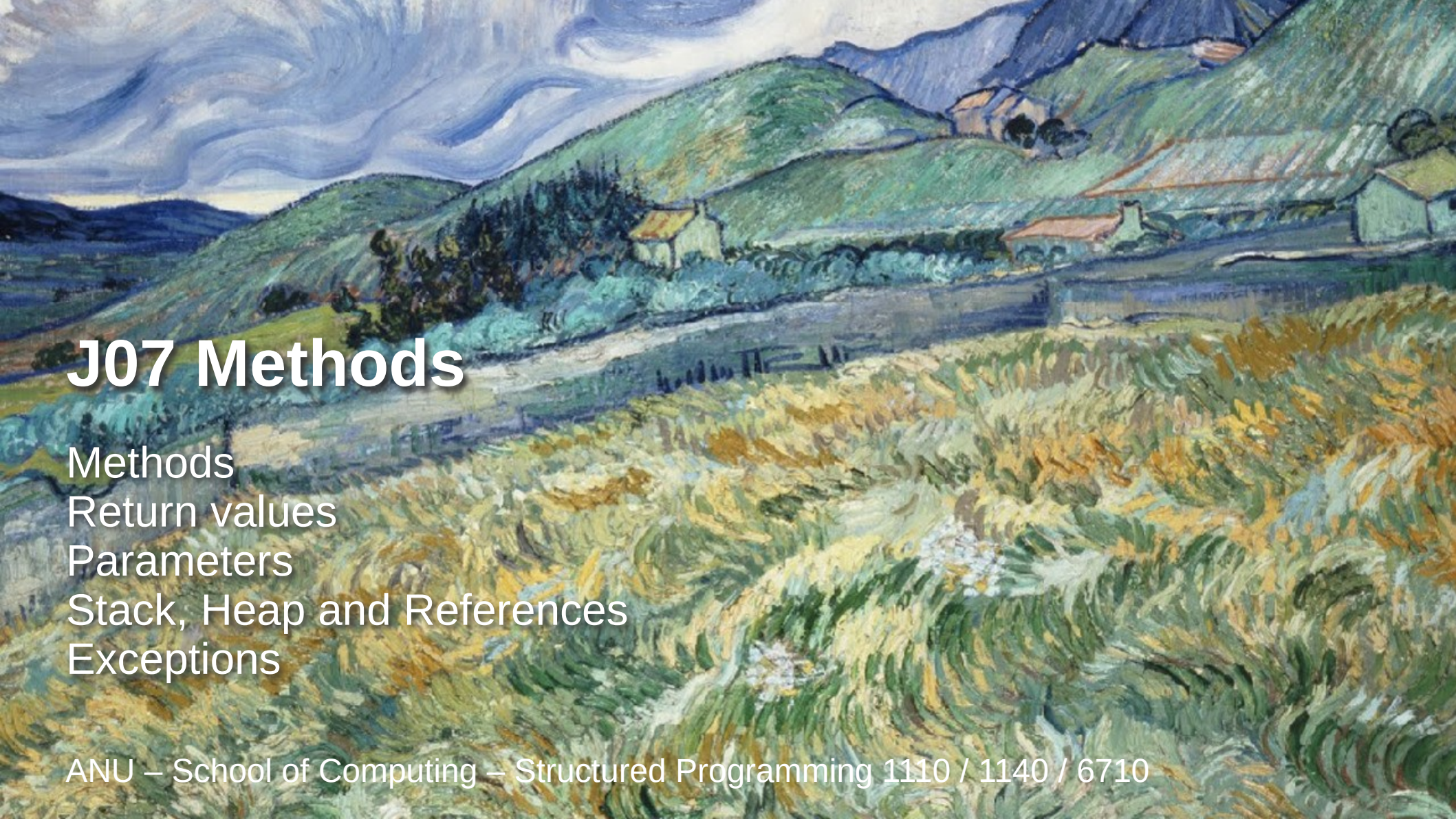
Structured programming: sequence, selection, **iteration**.

The `for` statement

- A compact way to *iterate* over a set of values.
- The statement has three logical parts:
  - Initialization
  - Continuation condition
  - Increment statement
- The *'enhanced'* for statement infers the initialization, termination and increment statements, given an array or collection

Branching statements

- The `break` statement terminates a loop construct
  - *Unlabelled* terminates the inner-most loop
  - *Labelled* terminates the loop named by the label
- The `continue` statement skips the current iteration of a loop
  - *Unlabelled* skips the current iteration of the inner-most loop
  - *Labelled* skips the current iteration of the loop named by the label
- The `return` statement exits the current method



J07 Methods

Methods
Return values
Parameters
Stack, Heap and References
Exceptions

Methods

- A subroutine
  - Reusable code to perform a specific task
  - Modularity, encapsulation
- May take arguments (parameters)
- May return a value

Method Declaration

Method declarations will have the following, in order:

- Any **modifiers** (`public`, `private`, etc.)
- **return type**
- **method name**
- **parameters**, in parentheses
- Any **exceptions** the method may throw
- The method **body** (code)

```
class String {…
 public byte[] getBytes(String charsetName) throws UnsupportedEncodingException {
 … }
… }
```

Class and Instance methods

A method declared with the `static` modifier is a **class method** (otherwise it is an **instance method**).

- Class methods
  - May operate on **class fields** only
- Instance methods
  - May operate on class and **instance fields**

Returning a Value from a Method

The `return` statement exits the current method.

Methods `return` to caller when:

- all statements in method executed, or
- a `return` statement is reached, or
- the method throws an exception (later)

Methods declared `void` do not return a value.

All other methods must return a value of the declared type (or a subclass of the declared type, described later).

Parameters (method arguments)

Parameters are the mechanism for passing information from one method to another method (or constructor).

The syntax is easy, following method declaration add pass values / variables to appropriate type in the correct order:

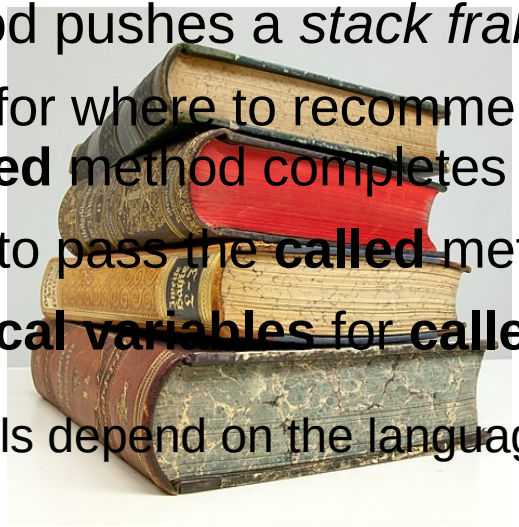
```
byte[] bytes = myString.getBytes(“UTF-8”);
```

The semantics of passing parameters is not so simple…

Warning! next few slides delve into some implementation details.

The Call Stack: Method after Method after…

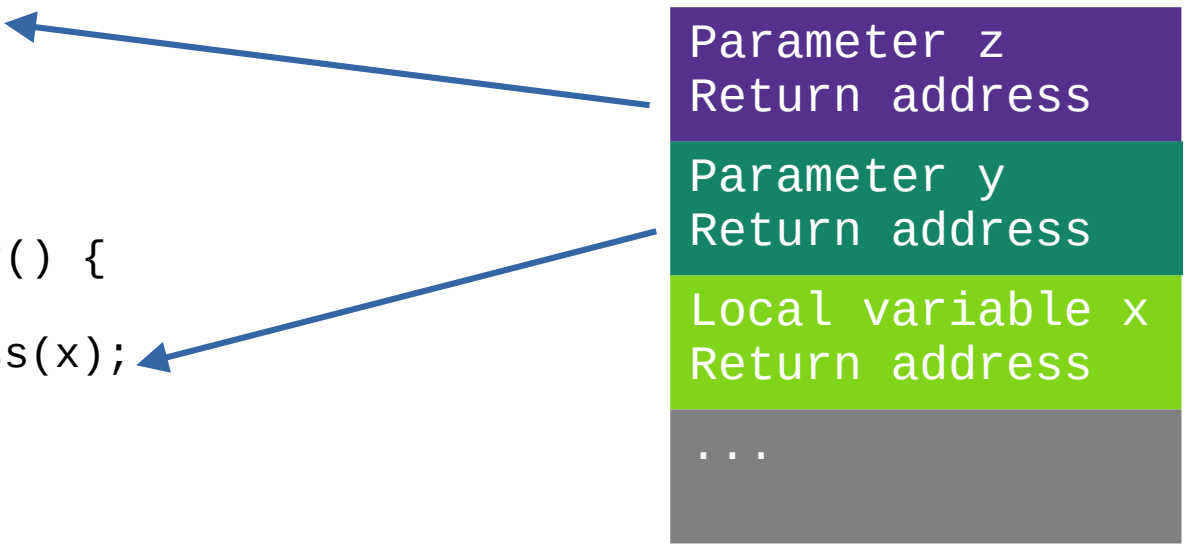
- Call Stack: a data structure that tracks method calls
  - Not directly interacted with in high-level languages like Java
  - Fast, efficient way to implement method calls
  - Each call to a method pushes a *stack frame* to the stack with*:
    - **Return address** for where to recommence execution in the **calling** method after **called** method completes
    - The **parameters** to pass the **called** method
    - Space to store **local variables** for **called** method



* Not specific to Java, the details depend on the language, compiler, instruction set, operating system etc...

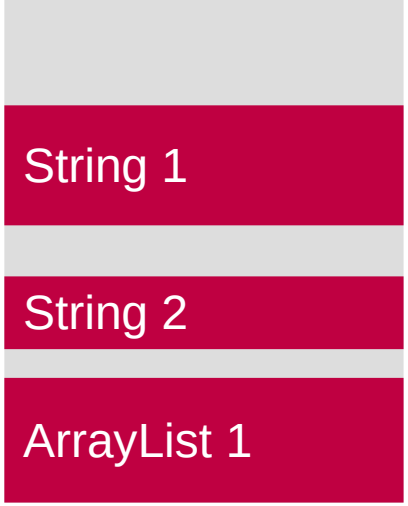
The Call Stack

```
static int twice(int z) {
    return 2 * z;
}

static int process(int y) {
    y = twice(y);
    y = y + 1;
    return y;
}

static int number() {
    int x = 100;
    return process(x);
}
```



The Heap

- In Java, objects (non-primative types) are *not directly* stored on the stack, rather they are stored (allocated) on *the heap*.
- **The heap**: a large region(s) of memory used to dynamically store objects, i.e. their instance fields.



Variables and References

Variables are for either:

- **Primitive Types**: value stored directly
- **Reference Types (all objects)**: “value” is a pointer / address to an object stored on the heap
  - We don’t directly interact with this pointer
  - Except, can be set to `null` (pointer to nowhere)
  - Method calls, fields automatically access the object pointed to
    - `NullPointerException` thrown if reference is `null`

Parameters

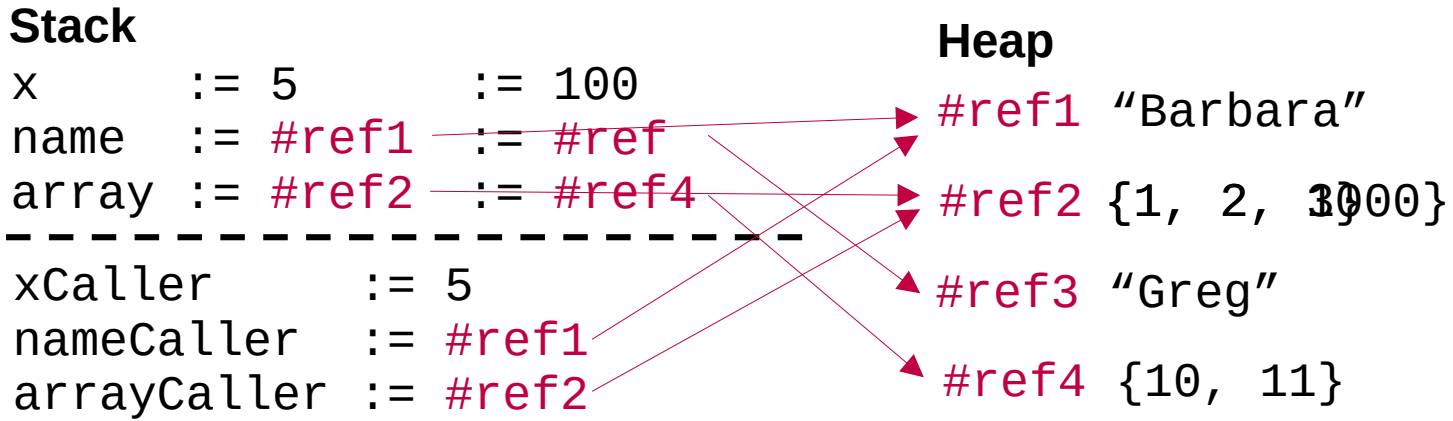
- **Primitive types** passed by value (copied into stack frame)
  - Changes to parameter are **not seen** by caller
- **Reference types** passed by value (copied into stack frame)
  - Changes to the *reference* are **not seen** by caller
  - Changes* to *object referred* to **are seen** by caller

* Some types (e.g., String) are designed to be *immutable* – no public methods modify any class or instance fields.

Parameter Passing

```
public static void main(…) {
    int xCaller = 5;
    String nameCaller = "Barbara"
    int[] arrayCaller = new int[] {1, 2, 3};
    method(xCaller, nameCaller, arrayCaller);
}
```

```
static void method(int x,
                   String name,
                   int[] array) {
    x = 100;
    name = "Greg";
    array[2] = 1000;
    array = new int[]{10, 11};
}
```



Exceptions Basics

- A method can either execute normally and return a value (passing execution back to caller), or throw an exception to signal something went wrong.
- When an exception is thrown, exception control flow kicks in: *unwinds* the call stack until either a method further down the stack “handles” the exception, or the process exits.
- We will revisit the types of exception and how to catch them later on. For now you will just likely want exceptions to crash your program so it is obvious something went wrong.

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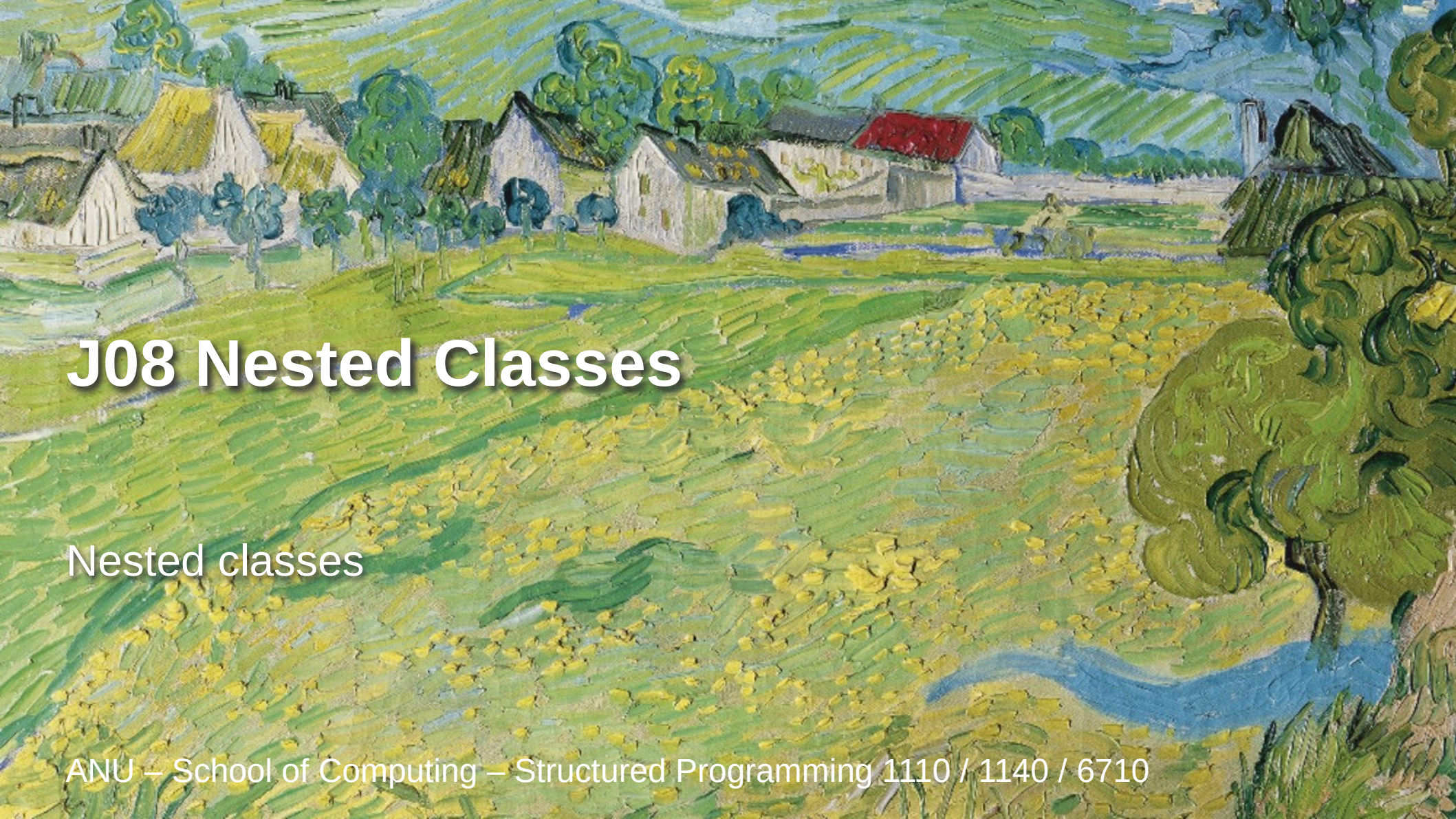


J08 Nested Classes

Nested classes

Nested Classes

A class may be defined within another class. Such a class is called a nested class. The main motivation for nested classes is to improve encapsulation and clarity.

- **Static nested classes** (use `static` keyword) behave as if declared elsewhere, but happen to be packaged together in a single file, cannot refer directly to instance fields of parent
- **Inner classes** (non-static) has direct access to the instance fields and members of its enclosing class.

J09 Lambda Expressions

Lambda expressions

Lambda Expressions

Lambda expressions allow code to be passed as a parameter, just like data.

- Particularly useful for *event handling*; can pass *behaviour* as an argument (‘do this when event “e” happens’).
- Syntax
  - Comma-separated formal parameters (x)
  - Arrow (->)
  - Body (either single expression or statement block, which may contain return)

```
x -> x > 100  or  x -> { … return true; }
```

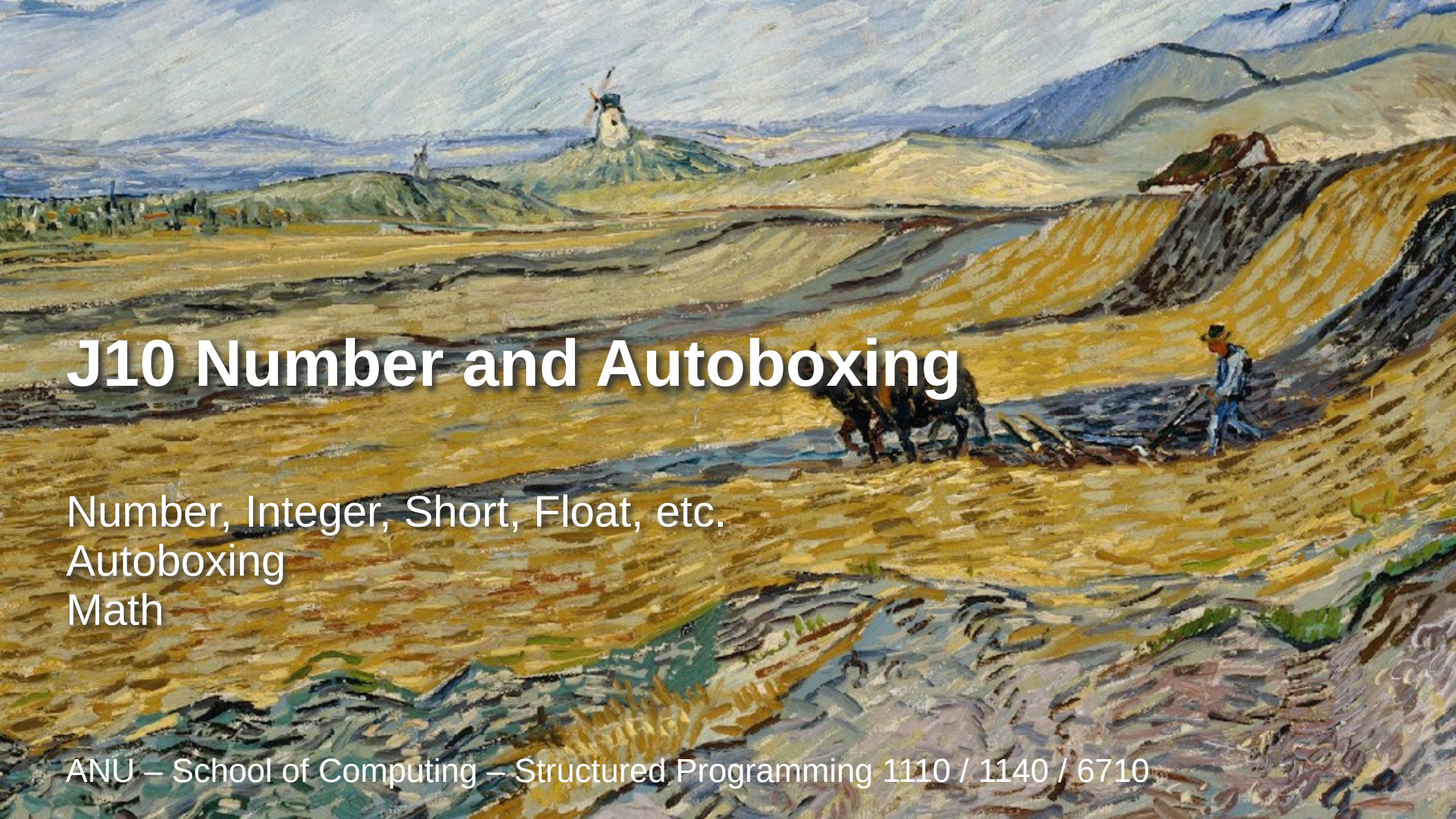
Functional Interfaces

A lambda expression implements a *functional interface*: an interface which only defines a single method.

Commonly-used functional interfaces are defined in package `java.util.function`, e.g.:

```
public interface IntPredicate {
    boolean test(int value);
}

public interface DoubleSupplier {
    double getAsDouble();
}
```



J10 Number and Autoboxing

Number, Integer, Short, Float, etc.
Autoboxing
Math

The `Number` Classes

Normally you will represent numbers with the **primitive** types `int`, `short`, `float`, etc. Java includes 'boxed' object analogues to each of these: `Integer`, `Short`, `Float`, etc.

- Number classes have methods (primitives don't)
  - `toString()`, `parseInt()`, etc.
- Number classes have constants
  - `Integer.MIN_VALUE`, `Short.MAX_VALUE`, etc
- Number classes have a space overhead
  - They are instantiated as true objects

Autoboxing

Classes such as `Integer` and `Character` are *boxed* versions of the primitive types `int` and `char` (primatives *wrapped* in an object). Java offers automatic support (syntactic sugar) for boxing and unboxing (wrapping / unwrapping).

- Boxing an `int` literal: `Integer i = 5;`
- Unboxing to an `int` variable: `int j = i;`

The `Math` class

The `Math` class contains methods and constants useful for basic mathematics:

- Constants: `Math.PI`, `Math.E`
- Trigonometry: `sin()`, `cos()`, etc.
- Rounding: `abs()`, `ceil()`, `floor()`, etc.
- Comparison functions: `max()`, `min()`
- Exponentials and logs: `exp()`, `log()`, `pow()`, etc.
- Random number generation: `random()`

J11 Character and String

Character and String

The `Character` Class

The `Character` class boxes `char`, just as `Integer` boxes `int`. It contains methods and constants useful for manipulating characters:

- Property methods: `isLetter()`, `isDigit()`, etc.
- Conversion: `toString()` (a single character string!)

Escape sequences are used to represent characters that have a special meaning in Java syntax:

- `\'` , `\"` , `\\`, `\n`, etc.

The `String` Class

The `String` class is provided by Java to store and manipulate strings (by contrast, in C, a string is simply an array of characters).

- Implicit creation from literal:

```
String x = "foo";
```

- Concatenation with “+”:

```
String y = x + "bar";
```

- `StringBuilder` class

Operations on Strings

- Strings are *immutable*: no operations modify original `String`
- Get `length` (number of characters):

```
if (x.length() > 3) ...
```

- Get a character with `charAt()`
- Get a substring with `substring()`
- Others: `split()`, `trim()`, `toLowerCase()`, etc.
- Finding: `indexOf()`, `contains()`, etc.
- Replacing: `replace()`, `replaceAll()`, etc.

J12 Generics

Generics

Generics

Sometimes it is useful to parameterize a class with a type, `T`.

Rather than `IntContainer`, `LongContainer`, etc. we can just write `Container<T>`, and then create instances of types such as `Container<Integer>`.

We can also create generic methods that accept type parameters:

```
static <T> void acceptSomeValue(T value) { … }
```

Prior to the introduction of Java generics, programmers often used Object as a work-around as it can refer to any non-primitive type.

Type Parameters

- By default, the only thing that is assumed about a type parameter `T` is that it is an object: i.e. it extends `Object`.
  - No primitives can be used as a generic type (big part of the reason for boxing primitives)
  - When working with a variable that has a generic type, all we can do is pass it around and call methods that are defined for `Object`.
- *Bounds* can be put on type parameters to make them “less generic”.
  - E.g., `public <T extends Number & MyInterface> void method(T t) {…}`
  - This **restricts** the types that can be used with the generic.
  - This **increases** the assumptions that can be made about a variable of this generic type.

J13 Type Inference

Generic type inference
Lambda expressions
Local variables

Type Inference

The Java compiler can infer many types from context, cutting down on boilerplate code, and simplifying refactoring.

Instantiating generic classes:

```
LinkedList<String> s = new LinkedList<>();
```

Generic methods:

```
public <T> void add(T value) { }

list.add("A String");
```


Local Variables

With the `var` keyword, Java can infer the type of a local variable from its initialization expression.

The most specific type is inferred.

```
var theAnswer = 42;
var bike = new Bike();
var mystery; // invalid – no initializer
var nothing = null; // invalid – too vague
```

Lambda Expressions

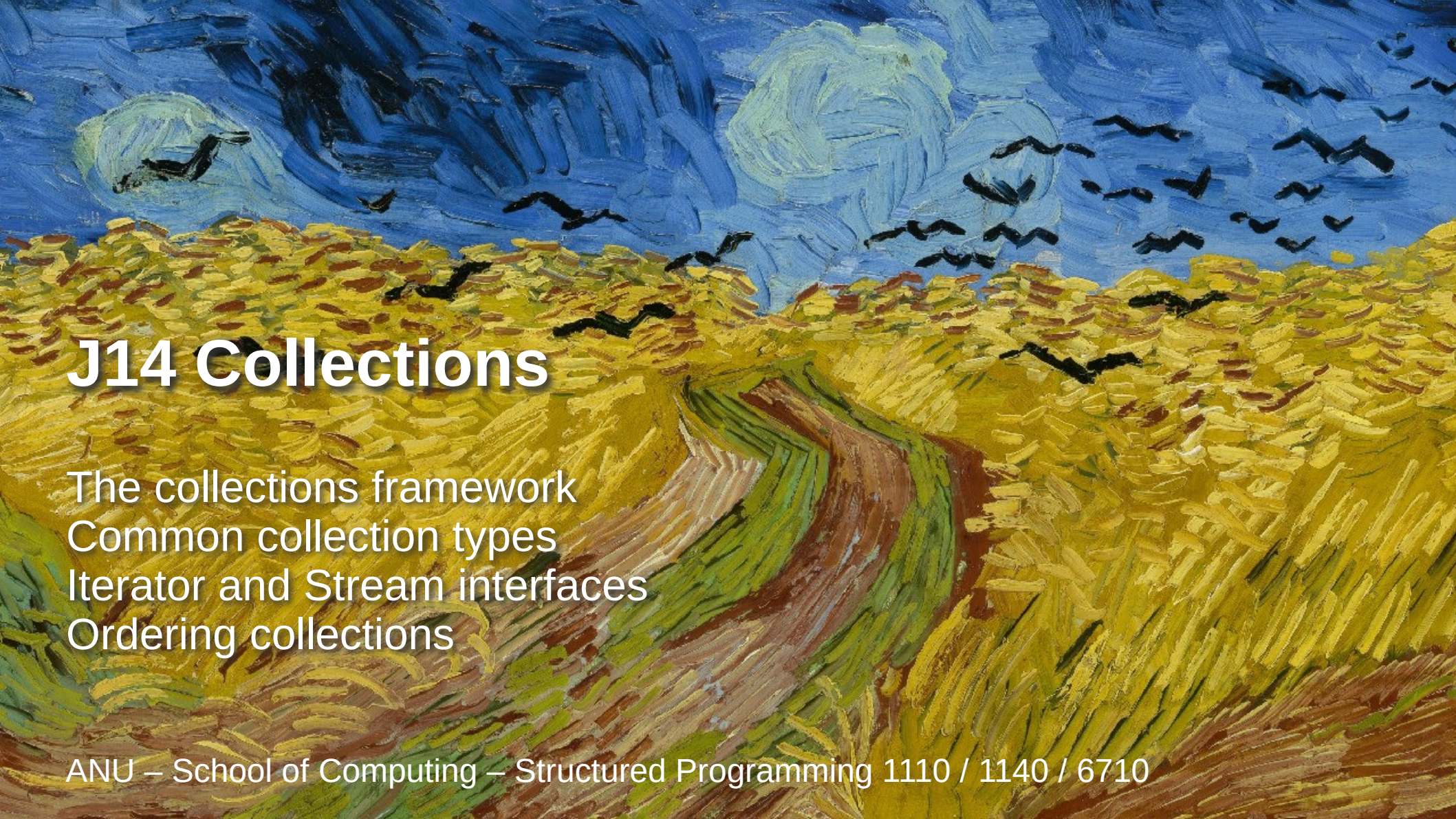
Types of **parameters** to lambda expressions:

```
Predicate<String> nonEmpty = x -> x.length() > 0;
```

However, **can't infer** the type of a lambda expression as a local variable:

```
var lambda = x -> x + 1; // invalid – what type is x?
var lambda = (int x) -> x + 1; // invalid – what is lambda?
IntFunction<Integer> lambda = x -> x + 1; // OK
```

Passing a lambda expression directly to a method normally works, as the method parameter provides the type information.



J14 Collections

The collections framework
Common collection types
Iterator and Stream interfaces
Ordering collections

The Collections Framework

- Interfaces
  - Implementation-agnostic interfaces for collections
- Implementations
  - Concrete implementations
- Algorithms
  - Searching, sorting, etc.

Using the framework saves writing your own: better performance, fewer bugs, less work, etc.

The Collection Interface

- Basic operators
  - `size`, `isEmpty()`, `contains()`, `add()`, `remove()`
- Traversal
  - for-each, and iterators
- Bulk operators
  - `containsAll()`, `addAll()`, `removeAll()`, `retainAll()`, `clear()`
- Array operators
  - convert to and from arrays

Collection Types

- Primary collection types:
  - **Set** (no duplicates, mathematical set)
  - **List** (ordered elements)
  - **Queue** (shared work queues)
  - **Map** (<key, value> pairs)
- Each collection type is defined as an interface
  - You need to choose a concrete collection
  - Your choice will depend on your needs

Concrete Collection Types

	Implemented Using				
Interfaces	**Hash table**	**Resizable array**	**Tree**	**Linked list**	**Hash table + linked list**
`Set`	`HashSet`		`TreeSet`		`LinkedHashSet`
`List`		`ArrayList`		`LinkedList`	
`Queue`		`ArrayDeque`		`LinkedList`	
`Map`	`HashMap`		`TreeMap`		`LinkedHashMap`

Based on table from http://docs.oracle.com/javase/tutorial/collections/implementations/index.html

Four Commonly Used Collection Types

- `HashSet` implements a **set** as a hash table
  - Makes no ordering guarantees
- `ArrayList` implements a **list** using an array
  - Very fast access
- `HashMap` implements a **map** using a hash table
  - Makes no ordering guarantees
- `LinkedList` implements a **queue** or **list** using a linked list
  - First-in-first-out (FIFO) queue ordering

`Iterable<T>` interface

Collections implement the `Iterable<T>` interface, which enables use of the “For-Each loop”:

```
for (var t : things) {
    System.out.println(t);
}
```

and also a `forEach` method to apply lambda expression:

```
things.forEach(t -> System.out.println(t));
```

`Stream<T>` Interface

Collections can accessed as a stream via the `stream()` method, enabling a more **functional programming** style:

```
List<Integer> list = List.of(1, 2, 3, 4, 5); // immutable list!
var count = list.stream()
                .filter(x -> x > 2)
                .count();
var nList = list.stream()
                .filter(x -> x > 2)
                .map(x -> Integer.toString(x + 2))
                .toList(); // immutable, otherwise collect(...)
```

Ordering Collections

The `Comparable` interface defines a ‘natural’ ordering for all instances of a given type, T:

```
public interface Comparable<T> {
    int compareTo(T o);
}
```

The return value is either negative, 0, or positive depending if the receiver comes before, equal, or after the argument, `o`.

The `Comparator` *functional* interface allows a type T to be ordered in ad-hoc ways:

```
public interface Comparator<T> {
    int compare(T o1, T o2);
}
```

java.util.Collections

Some useful static methods for collections:

- `sort`, `min`, `max`, `reverse`, `frequency`, `addAll`

`List` also has a `sort` instance method:

- When provided with `null` it uses the natural order of elements (given by `Comparable`)
- Can use bespoke ordering when provided a lambda expression (`Comparator` functional interface):

```
(T a, T b) -> { return <expression>;}
```

Josh Bloch Item 25: Prefer lists to arrays

Why?

- Arrays are *covariant*, Generics are *invariant*
  - if `A extends B`, then `A[]` is a subclass of `B[]`
  - but `List<A>` has no relationship to `List<B>`

```
// Fails at runtime!
Object[] array = new Long[1];
objectArray[0] = "I don't fit in"; // Throws ArrayStoreException

// Won't compile!
List<Object> list = new ArrayList<Long>(); // Incompatible types
list.add("I don't fit in");
```

J15 Exceptions

Java Exceptions
Catch or Specify
Java syntax

Exceptions

Exceptions are a **control flow construct for error management**.

Some similarity to event handling (lecture topic **X02**)

- Both disrupt the normal flow of execution, transferring to event handler or exception handler
- However: exceptions are exceptional situations (events are expected)
  - A file is not found or is inaccessible
  - An array is accessed incorrectly (out of bounds)
  - Division by zero
  - A null pointer is dereferenced, etc.

Java Exceptions

Exceptions are *thrown* either:

- Implicitly (via a program error) or
- Explicitly (by executing the `throw` statement).

Exceptions are *caught* with a `catch` block.

Exceptions are propagated from callee to caller (call stack is *unwound*) until a matching handler is found.

Kinds of Java Exception and Compile-time Check

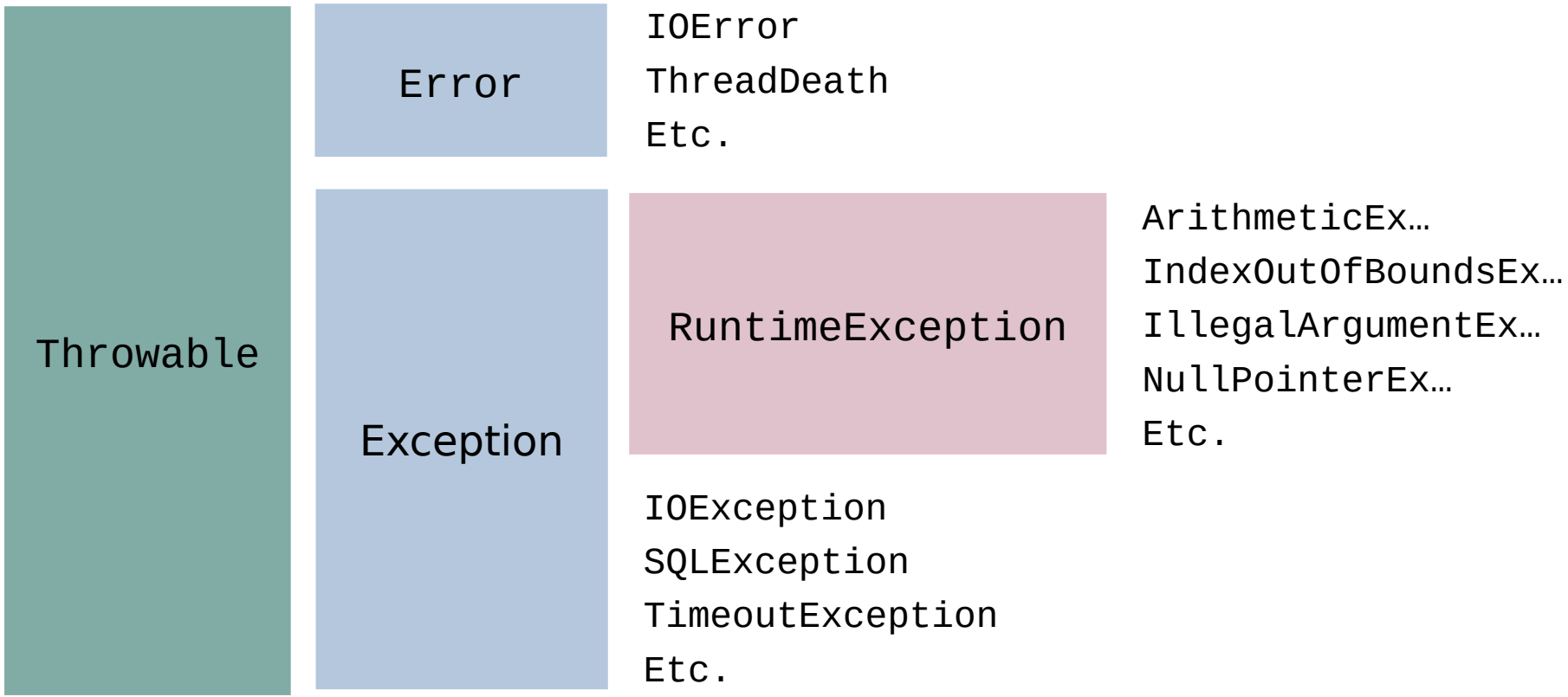
- **error** (`Error` and its subclasses),
  - serious problems that a reasonable application probably shouldn't attempt to catch
- **runtime exception** (`RuntimeException` and its subclasses),
  - exceptional situation that often cannot be anticipated or recovered from (e.g., program bugs, logic error, API misuse): probably should fix the bug rather than catch
- **checked exception** (everything else)
  - can be thrown during normal operation and can be reasonably anticipated and handled

unchecked exceptions

Code that may throw a checked exception must comply with the **catch or specify** requirement, i.e. must be enclosed by either:

- a `try` statement with a suitable handler, or
- a method that declares that it `throws` the exception

Java Exception Type Class Hierarchy



Java `try`/`catch` Block Syntax

```
try {
  // do something that may generate an exception
} catch (ArithmeticException e1) {  // first catch
  // this is an arithmetic exception handler
  // handle the error and/or throw an exception
} catch (Exception e2) {  // may have many catch blocks
  // this an generic exception handler
  // handle the error and/or throw an exception
} finally {
  // this code is guaranteed to run
  // if you need to clean up, put the code here
}
```


J16 Java Threads

Thread and Runnable
start(), join() and sleep()
Races and synchronized

Thread and Runnable

- The `Thread` class is used to create threads and interact with them.
- Two ways to create a thread:
  - Subclass `Thread`, overriding its `run()` method.
    - Correspondence between instances of the class and threads.
    - Disadvantages: can't subclass anything else.
  - Use the `Runnable` interface and implement its `run()` method.
    - Use `Thread.currentThread()` to access the thread that is executing the `run()` method.

`start()`, `join()` and `sleep()`

- Calling `t.start()` will start execution of the run() method within the thread t (then continue execution of the current thread).
- Calling `t.join()` will cause the current thread to wait until thread t terminates.
- Calling `Thread.sleep(ms)` will cause the current thread to go to sleep for ms milliseconds.

Races and the `synchronized` keyword

- Too many cooks…
  - Coordination is the big challenge of concurrency
  - How do we avoid conflicts?
  - How do we impose some level of coherence and order?
- A ‘race condition’ is a situation where one or more threads race non-deterministically to be the first to read or write a variable
- The `synchronized` keyword
  - Qualify a method, ensures only one thread executes that method at any time