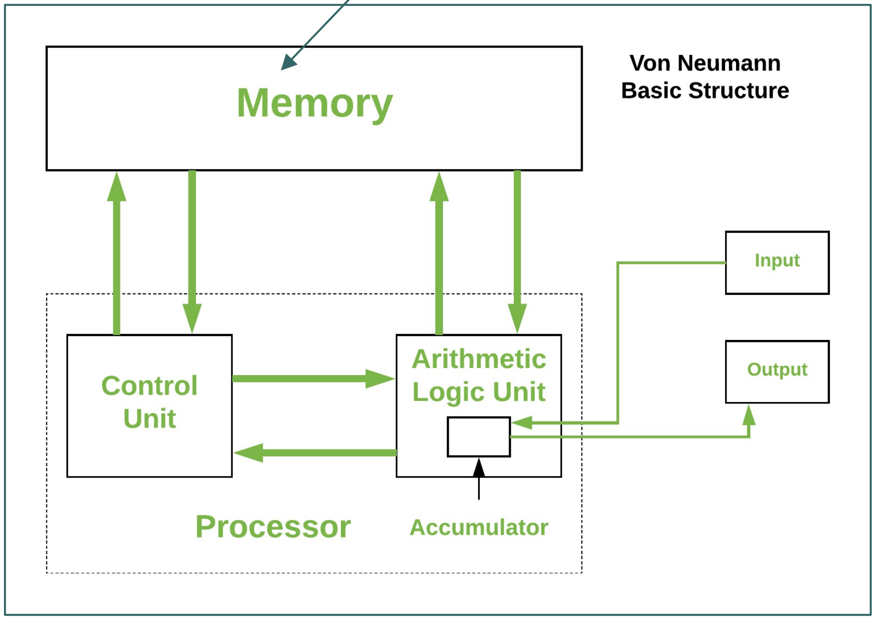
Imperative Programming – Foundations

- The origins of imperative programming
- Types

The von Newman Architecture

John von Newman, Hungarian mathematician, 1903-1957.

State



- John von Newman's computing model gave rise to the notion of imperative programming
- Assembly/machine instructions directly manipulate processor memory
  - Imperative in the sense that each instruction states what memory will look like after it executes
- The contents of the memory defines the state of the computation at any particular point in time

Image source: https://www.geeksforgeeks.org/computer-organization-von-neumann-architecture

The von Newman Architecture

```
section .data
    x dw 1
    y dw 2

section .bss
    z resw 1

section .text
    global _start

_start:
    mov ax, [x]     ; fetch x
    add ax, [y]     ; fetch and add y
    mov [z], ax     ; store result in z

    ; exit the program
    mov eax, 1
    xor ebx, ebx
    int 0x80
```

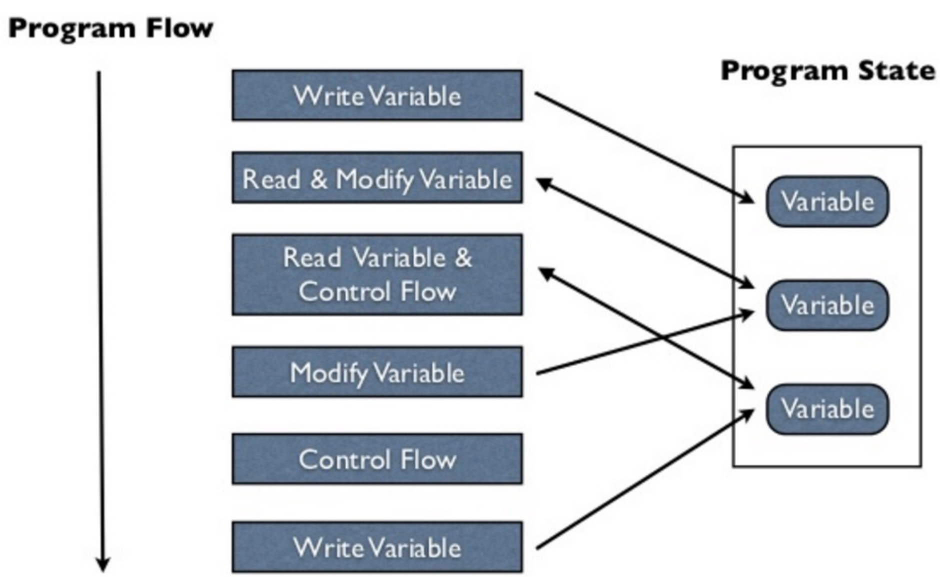
- Memory state is defined by three three memory **locations**
  - x,y,z
- The program changes the state by storing the sum of locations x and y into location z
- Here [<location name>] means reading/writing the value stored at that location

Imperative Programming – Foundations

- In higher-level languages memory locations are abstracted into variables
  - This includes array/list variables
- Assembly/machine instructions are abstracted into programming language syntax
  - BUT, the assignment statement is still imperative, it tells us exactly what memory looks like after it executes.

```
let x = 1.
let y = 2.
let z = x + y.
```

Imperative Programming – Foundations



Imperative programming –

- Explicit statements that change the program state
- The program state is defined by the values assigned to the variables in a program
- The most common way to change the state in imperative programming is through an **explicit assignment of a new value to an existing variable**

Image source: https://practical.li/clojure/concepts/what-is-functional-programming.html

Imperative Programming – Foundations

- Another example of an imperative program

```
-- sum the elements of a list
load system io.

-- initialize state
let lst = [1,2,3].
let sum = 0.

-- modify state each time around the loop by
--   (1) assigning a new value to x from the list
--   (2) incrementing sum by x
for x in lst do
    let sum = sum + x.
end

io @println sum.
```

ln002/sum1.ast

Imperative Programming – Foundations

- Let’s review basic type theory for programming languages
- This is important in order to understand
  - Type hierarchies
  - Type checking
  - Type promotion

Reading

- Section 1 of the paper “Type Systems” by Luca Cardelli, Microsoft Research
  - lutzhamel.github.io/CSC493/docs/typesystems.pdf

Types

A Type is a Set of Values

Consider the Rust statement:

```
let n : i32 = 3;
```

Here we constrain n to take on any value from the set of all 32bit integer values.

Types

Def: A type is a set of values.

Def: A primitive type is a type that is built into the language, e.g., integer, string.

Def: A constructed type is a user defined type, e.g., any type introduced by the user.
In Asteroid this is done through the 'structure' statement.

Example: Asteroid, primitive type

$\underbrace{\text{q:\%real}}_{}$ = 1.1;

q is of type real, only
a value that is a member
of the set of all real
values can be assigned to q.

type real ⇒ set of all
possible real values

Types

Example: Rust, constructed type

```
struct Rectangle {
    xdim: i32,
    ydim: i32,
}

fn main() {
    let r:Rectangle = Rectangle { xdim: 3, ydim: 4 };
}
```

Now the variable r only accepts values that are members of type Rectangle;
☞ object instantiations of struct Rectangle.

Types

Example: Asteroid, constructed type

```
structure Rectangle with
  data xdim.
  data ydim.
end

let r:%Rectangle = Rectangle(4,2).
```

an element of
type Rectangle.

Subtypes

Def: a <u>subtype</u> is a <u>subset</u> of the elements of a type.

<u>Example</u>: C

Short is a subtype of int: short < int

> The notation A < B means A is a subtype of B.

<u>Observations</u>:

(1) converting a value of a subtype to a values of the super-type is called <u>widening</u> type conversion. (safe)

(2) converting a value of a supertype to a value of a subtype is called <u>narrowing</u> type conversion. (not safe)

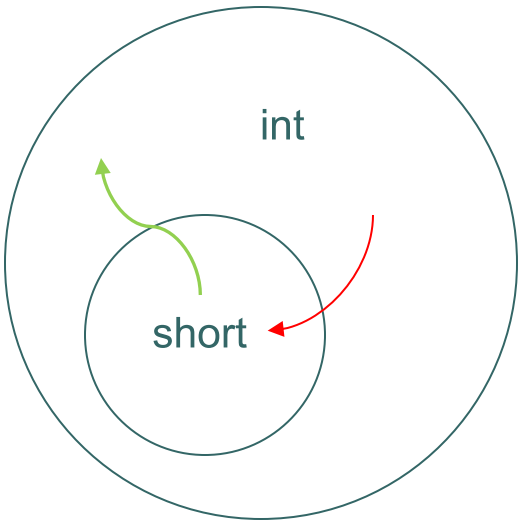
<u>Example</u>: C, partial type hierarchy

char < short < int < float < double

> Subtypes give rise to type hierarchies and type hierarchies allow for automatic type coercion – widening conversions!

Subtypes

- A convenient way to visualize subtypes is using Venn diagrams
- Consider,
  short < int
- It is easy to see that the shorts are a subset of the integer values
- The green arrow represents a widening type conversion is always safe
- The red arrow represents a narrowing type conversion and is never safe



e.g. In Rust we have i16 < i32

Why do we use types?

- Types allow the language system to assist the developer write better programs. Type mismatches in a program usually indicate some sort of programming error.
  - Static type checking – check the types of all statements and expressions at compile time.
    - Rust
  - Dynamic type checking – check the types at runtime.
    - Asteroid
    - Python

Type Equivalence

- Fundamental to type checking is the notion of type equivalence:
  - Figuring out whether two type description are equivalent or not
  - This is trivial for primitive types
  - But not so straight forward for constructed types like class/struct objects.

Type Equivalence

I. Name (nominal) Equivalence – two objects are of the same type if and only if they share the same type name.

Example: Rust – constructed type

```
struct Type1 {x:i64, y:i64}
struct Type2 {x:i64, y:i64}

fn main () {
    let x: Type1 = Type1{x:1,y:2};
    let y: Type2 = x;
    println!("{:?}",y);
}
```

Error; even though the types look the same, their names are different, therefore, Rust will not compile.

☞Rust uses name equivalence

Type Equivalence

II. Structural Equivalence – two objects are of the same type if and only if they share the same type structure.

Example: Haskell

```haskell
type Type1 = (Integer, Integer)
type Type2 = (Integer, Integer)

x :: Type1
y :: Type2

x = (1,2)
y = x
```

Even though the type names are different, Haskell correctly recognizes this statement.

☞ Haskell uses structural equivalence.

Type checking

- Type checking refers to the process of making sure that all expressions and statements are properly typed.

Type Checking

- Here is the Python type checker in action
  - int and str are not part of a common type hierarchy.

```
Python 3.8.10 (default, Nov 14 2022, 12:59:47)
[GCC 9.4.0] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>> "my string" + 1
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: can only concatenate str (not "int") to str
>>>
```

Type Checking

- Here is the type checker of the Rust compiler in action
  - i16 < i32

```
fn main () {
    let x:i32 = 3;
    let y:i16 = 2*x;
    print!("{}",y);
}
```

```
ubuntu$ rustc assign.rs
error[E0308]: mismatched types
 --> assign.rs:3:16
  |
3 |     let y:i16 = 2*x;
  |           ---   ^^^ expected `i16`, found `i32`
  |           |
  |           expected due to this
  |
help: you can convert an `i32` to `i16` and panic if the converted value wouldn't fit
  |
3 |     let y:i16 = (2*x).try_into().unwrap();
  |                 ^^^^^^^^^^^^^^^^^^^^^^^^^

error: aborting due to previous error

For more information about this error, try `rustc --explain E0308`.
ubuntu$
```

Type Checking in Asteroid

- The Asteroid type checker in action
  - Integer < real

```
Asteroid Version 1.1.4
(c) University of Rhode Island
Type "asteroid -h" for help
Press CTRL-D to exit
ast> let x:%real = 3.1.
ast> let y:%integer = x.
error: pattern match failed: expected type 'integer' got a term of type 'real'
ast> 
```

Type Promotion

- Convert a subtype to a supertype (automatically)
  - Widening conversion
- This usually happens at the operator level

Type Promotion - Python

- The addition operation is only defined for operands of the same type
- In order to apply the operator in a mixed-type situation one of the operands needs to be promoted
  - If promotion is not possible then flag a type error

```
Python 3.8.10 (default, Nov 14 2022, 12:59:47)
[GCC 9.4.0] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>> isinstance(3.5 + 1, float)
True
>>>
```

Promotion int → float

Type Promotion - Asteroid

```
Asteroid Version 1.1.4
(c) University of Rhode Island
Type "asteroid -h" for help
Press CTRL-D to exit
ast> load system type.
ast> type @gettype (3.5 + 1).
real
ast>
```

Promotion integer → real

Type Promotion – Rust

- Rust does not perform any automatic type promotion!

```rust
fn main () {
    let x = 3.5 + 1;
    println!("{}",x);
}
```

Explicit conversion

```rust
fn main () {
    let x = 3.5 + 1 as f64;
    println!("{}",x);
}
```

```
ubuntu$ rustc promote.rs
error[E0277]: cannot add an integer to a float
 --> promote.rs:2:16
  |
2 |     let x = 3.5 + 1;
  |                 ^ no implementation for `{float} + {integer}`
  |
  = help: the trait `std::ops::Add<{integer}>` is not implemented for `{float}`

error: aborting due to previous error

For more information about this error, try `rustc --explain E0277`.
ubuntu$
```

Imperative Programming – Asteroid

- Let’s take a closer look at the imperative aspects of Asteroid
- We start with the type system

Primitive Types & Constants in Asteroid

- Constants are available for all the primitive data types,
  - integer, e.g. 1024
  - real, e.g. 1.75
  - string, e.g. "Hello, World!"
  - boolean, e.g. true

Type Hierarchies

- Asteroid arranges primitive data types in a type hierarchy,
  - boolean < integer < real < string
- As we have seen, type hierarchies facilitate automatic type promotion

```
let x:%string = "value: " + 1.
```

ln002/let2.ast

Type promotion: plus as string concatenate op

Structured Data Types

- Asteroid also supports the built-in data types:
  - list
  - tuple
- These are structured data types in that they can contain entities that belong to other data types.
- Lists are mutable objects whereas tuples are immutable.
- Some examples,

Note: (1,) ≠ (1)

```
let l = [1,2,3]. -- this is a list
let t = (1,2,3). -- this is a tuple
let one_tuple = (1,). -- this is a 1-tuple
```

ln002/let1.ast

Structured Data Types

- Lists and tuples themselves are also embedded in type hierarchies, although very simple ones:
  - list < string
  - tuple < string
- That is, any list or tuple can be viewed as a string. This is very convenient for printing lists and tuples,

```
Asteroid Version 1.1.4
(c) University of Rhode Island
Type "asteroid -h" for help
Press CTRL-D to exit
ast> load system io.
ast> io @println ("this is my list: " + [1,2,3]).
this is my list: [1,2,3]
ast>
```

The None Type

- Asteroid supports the none type.
- The none type has only one member
  - A constant named none.
  - The empty set of parentheses () can be used as a shorthand for the none constant.
  - That is: none = ()

The None Type

- The none type plays an important role in many modern programming languages
  - Python: NoneType – None
  - Rust: Unit – ()
  - Asteroid: none – none or ()
- The none type is employed when something like a function needs to return a value, but no such value exists, e.g. Python

```
>>> from types import NoneType
>>> def foo():
...     pass
...
>>> type(foo()) is NoneType
True
>>>
```

https://en.wikipedia.org/wiki/Unit_type

Other Data Types

- In Asteroid we also have additional data types:
  - function
  - pattern
  - user defined data types via structures

```
load system type.

-- define a function
function inc with x do
    return x+1.
end

-- show that 'inc' is of type 'function'
assert (type @gettype(inc) == "function").
```

ln002/ftype.ast

Reading

- The Basics
  - asteroid-lang.readthedocs.io/en/latest/User%20Guide.html#the-basics