F28PL1 Programming Languages

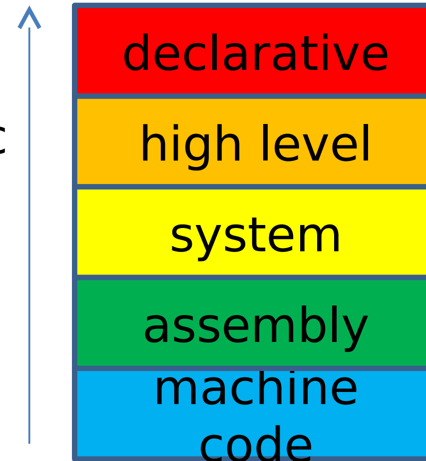
Lecture 20: Summary

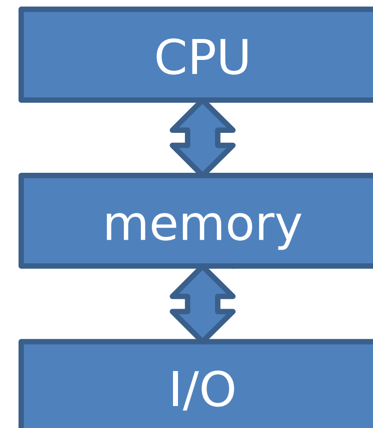
Overview

- started by characterising a computer as a memory machine
- considered programming languages as abstractions from:
  - memory as address/byte associations
  - instructions as sequences of changes to address/byte associations

Overview

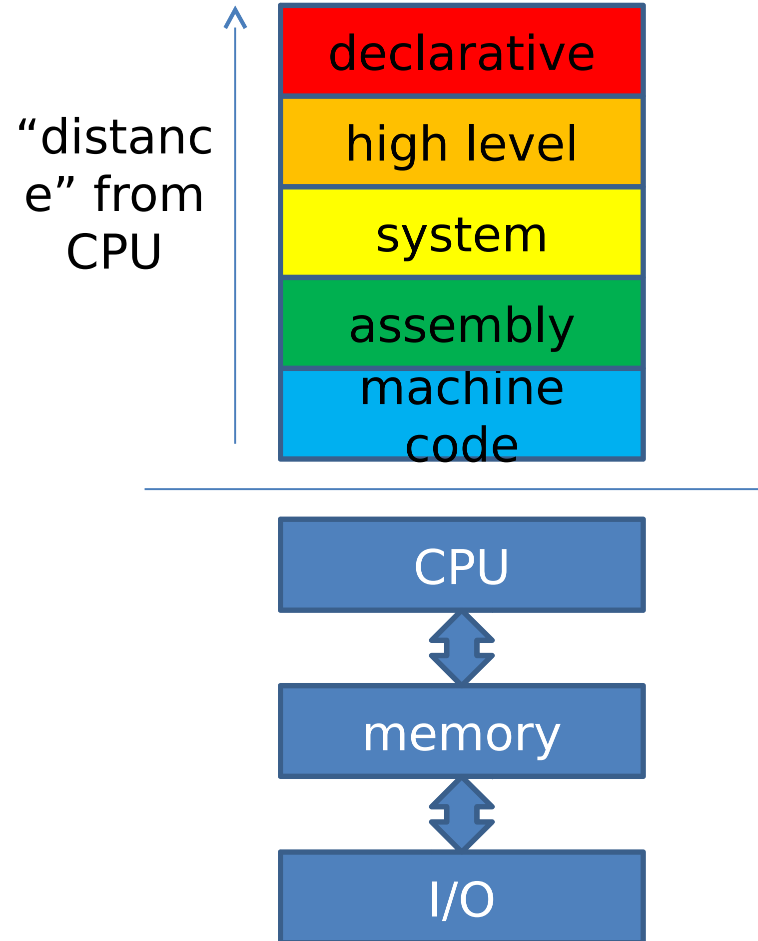
- layers of abstraction
- hierarchy of expressiveness
- tension between:
  - expressive power/ease of use
  - ease of implementation/ performance





Overview

- greater distance from CPU ㅍ
  - increased expressiveness/ succinctness
  - increased implementation effort
  - decreased performance
  - more memory
  - less speed



Summarising language characteristics

- how does a language abstract away from underlying byte machines?
  - types
  - data abstraction
  - control abstraction
- what are pragmatic consequences of language characteristics?
  - i.e. how do characteristics affect use?

Types

- values & operations
- what are *base* types?
  - e.g. Java: int, float, char etc
- what are *structured* types?
  - e.g. Java: object, array, String etc

Types

- how do types constrain language?
- *weak* v *strong* typing
  - i.e. whether type associated with entity can change (weak) or can't change (strong)
  - e.g. Java: strong typing
- *static* v *dynamic* typing
  - i.e. whether types checked at *compile time* (static) or *run time* (dynamic)
  - e.g. Java: static typing

Polymorphism

- type abstraction
  - can types be generalised?
  - *polymorphism* == many shapes
- *ad-hoc* v *parametric* polymorphism
  - ad-hoc == “for this”
  - i.e. language/context specific
  - parametric == controlled by parameters

Polymorphism

- e.g. Java
  - ad-hoc polymorphism
  - operator overloading
  - i.e. can use some operators with different types e.g. arithmetic
  - parametric polymorphism
  - i.e. generic types with type variables

Assembler summary: types

- no types
  - everything is a byte
- *representations* for:
  - numbers, characters etc
- no type checking
  - representation are *conventional*
  - can apply any operation to any byte sequence regardless of representation
  - i.e. ad-hoc polymorphism

C summary: types

- strong, static types
  - but... can override types with casts & address manipulation
- base types
  - int, short, long, char, float, double
- structured types
  - array, struct, pointer, union, function
- ad-hoc polymorphism
  - operator overloading & cast

SML summary: types

- strong, static types
- base types
  - int, real, char, bool
- structured types
  - tuple, list, user defined
- ad-hoc polymorphism
  - operator overloading
- parametric polymorphism
  - functions, lists, user defined types

Prolog summary: types

- weak, dynamic types
- base types
  - integer, atom
- structured types
  - structure, list
- ad-hoc polymorphism
  - arbitrary types can appear in structures

Data abstraction

- memory abstraction
- variable as name/value abstraction from address/contents
  - e.g. Java: variables
- where may variables be introduced?
  - e.g. Java: class fields, method formal parameters, block/method bodies, iteration control

Data abstraction

- how may variables be bound to values?
- e.g Java:
  - initialising declaration
  - assignment
  - parameter passing

Data abstraction

- *scope*
  - i.e. where is something visible?
  - *lexical* v *dynamic* scope
  - i.e. constrained or not by site of definition/declaration
- *extent*
  - i.e. how long does something exist?

Data abstraction

- e.g. Java: lexical scope
  - class field/method names visible via object
  - variables in block/ method body visible in block unless redefined
  - method formal parameter visible in method body only
- e.g. Java: block extent
  - variables only exist in defining block/method body

Assembler summary: data abstraction

- names `R0-R15`, `PC`, `LR`, `SP` etc abstract from CPU registers
- labels abstract from memory addresses
- names and labels used as variables
- i.e. use name as operand to access/change register/memory
- no data structures
  - must craft explicitly from byte sequences

Assembler summary: data abstraction

- registers:
  - scope/extent - whole program
- labels:
  - scope whole file + where imported
  - extent – whole program

C summary: data abstraction

- variable
  - name/value association
  - abstracts address/contents
- can still expose low level memory:
  - & and *
  - can request that variable be bound to register

C summary: data abstraction

- variable introduction
  - declaration at start of program
  - declaration at start of block
  - formal parameters
- scope
  - lexical
- extent
  - block

SML summary: data abstraction

- variable
  - name/value association
  - cannot be changed
- address/memory not visible

SML summary: data abstraction

- variable introduction
  - global definition
  - local definition
  - formal parameter
- scope
  - lexical
- extent
  - local definition, function body,

Prolog summary: data abstraction

- variable
  - name/value association
  - changed by backtracking
  - variable sharing
- memory not visible

Prolog summary: data abstraction

- variable introduction
  - term
- scope
  - lexical
- extent
  - goal of which term is part

Control abstraction

- structured operations as commands
- how are calculations performed?
  - e.g. Java: expression
- how is memory accessed?
  - e.g. Java: use variable name in expression context
- how is memory changed?
  - e.g. Java: assignment to variable

Control abstraction

- how are commands structured?
- e.g. Java:
  - sequence
  - block, nested method calls
  - choice
  - if, switch
  - repetition
  - while, for, iterators, recursion

Control abstraction

- e.g. Java
  - control flow
  - method call, return & break
  - procedural
  - void method
  - i.e. from control sequences
  - functional
  - method with return type
  - i.e. from expressions
  - call by reference parameter passing

Program abstraction

- encapsulation
  - abstract over data & control
- e.g. Java
  - classes/objects

Assembler summary: control abstraction

- operators abstract from machine code
- must craft structured constructs from operator sequences
- no universal standards or conventions
  - but compilers/operating will define standards
  - e.g. for parameter passing

C summary: control abstraction

- expressions
  - abstract from arithmetic/logic sequences
- commands
  - abstract from:
  - memory/register manipulation sequences
  - flag test, branch & address

C summary: control abstraction

- commands
  - assignment
  - sequence
  - block & function body
  - choice
  - if & switch
  - repetition
  - for & while
  - flow of control
  - function call, return, break & goto

C summary: control abstraction

- functions
  - functional abstraction
  - with return type
  - procedural abstraction
  - no return type
  - call by value & by reference parameter passing

SML summary: control abstraction

- expressions
  - abstract from arithmetic/logic/flow of control sequences
- conditional expression
- pattern matching
  - abstracts from constant matching
- functions
  - call by value parameter passing
- recursion

Prolog summary: control abstraction

- term
  - abstracts from arithmetic/logic/flow of control sequences
- DB
  - disjunction of facts/rules
- rule body/question
  - conjunction of terms
- pattern matching
  - abstracts from constant matching

Prolog summary: control abstraction

- question/goal/sub-goal
  - analogous to function call
  - binds variables to terms
- recursion
- backtracking
  - reverses variable bindings

Pragmatics

- what is mapping to byte machine?
- how implemented?
- how easy to read/write/debug?
- performance?
- use?
- etc...

Assembler summary: pragmatics

- direct machine code abstraction
- 1 to 1 mapping from assembly language to machine code
- easier to program than machine code
- must be assembled to machine code
- very fast
  - same as machine code

Assembler summary: pragmatics

- hard to read/write/debug
- CPU specific
  - not portable
  - 1950s attempts at universal machine code (UNCOL) failed
- used for mission/system critical software
  - e.g. device drivers, BIOS, small embedded systems

C summary: pragmatics

- in-between assembler & high-level
- one to many mapping from command to machine code
- must be compiled to machine code (or interpreted)
- easier to read/write/debug than assembler
- can manipulate low level byte machine
- weak typing ⇒ errors from pointers & casts
- must manage memory explicitly
  - e.g. allocate free memory for dynamic structures

C summary: pragmatics

- not as fast as assembler
- CPU independent
  - ISO standard
  - mostly portable
  - but size of type depends on implementation
- used for system level programming, real-time/embedded control
- rapidly replacing assembler for lower-level programming

SML summary: pragmatics

- higher level than imperative programs
- many to one mapping from expression to machine code
- must be compiled to machine code (or interpreted)
- very succinct
- strong typing ⇒ reduces run-time errors
- good correspondence between program structure & data structure
- automatic memory management
  - garbage collection

SML summary: pragmatics

- not as fast as some imperative languages
  - garbage collection overhead
- CPU independent
  - formal definition
  - highly portable
- used for:
  - rapid prototyping
  - reasoning about programs
  - designing parallel frameworks e.g. Google map-reduce

Prolog: pragmatics

- higher level than imperative programs
- many to one mapping from expression to machine code
- must be compiled to machine code (or interpreted)
- very succinct
- good correspondence between program structure & data structure
- automatic memory management
  - garbage collection

Prolog: pragmatics

- weak types/static typing/ad-hoc polymorphism
  - space overhead: must have explicit representation on type in memory
  - time overhead: must check types for typed operation
- backtracking
  - space overhead: must keep track of execution history
- garbage collection overhead

Prolog: pragmatics

- very different model to imperative/functional languages
  - long way from von Neumann model
  - key concepts drawn from logic
- claims to be entirely implementation independent but need to understand:
  - variable sharing
  - backtracking

Prolog: pragmatics

- CPU independent
  - ISO standard
  - highly portable
- used for:
  - rapid prototyping
  - AI

Language choice

- formally, programming language choice is arbitrary
- *Church-Turing thesis*
  - all formal models of computability are equivalent
- thesis, not a theorem
  - can’t be proved as unknown number of models
- simplest way is to demonstrate *Turing completeness*
  - show model can be used to implement an arbitrary *Turing Machine*
  - Alan Turing’s 1936 model for computability

Language choice

- ***all*** models of computability so far have been shown to satisfy Church-Turing thesis
- including:
  - lambda calculus
  - recursive function theory
  - generalised von Neumann computers
  - programming languages with arbitrarily large values/structures
- so, in principle, can do anything in any programming language
- but…

Technical constraints on language choice

- language may not support key constructs
  - e.g. lower level system/platform manipulation/control
  - e.g. high level control abstractions suitable for parallelism
- language may not be supported on mandated platform
- implementation may not be able to deliver required performance
- implementation may not have particular:
  - functionality
  - libraries
- could fix these but adds time/effort/cost to project

Social constraints on language choice

- may prefer one language over another
  - why do you prefer the language?
  - not necessarily a good basis for choice…
- language may be mandated by:
  - employer
  - customer
  - either may have:
  - substantial investment in specific language technology
  - requirement for specific system/platform/external interoperability

Socio-technical constraints on language choice

- need to be future proof
- language should be:
  - stable
  - widely used
  - widely supported by different platform/language tool manufacturers