Summer School on Language-Based Techniques for Integrating with the External World

Introduction

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Welcome!

1st of 30 lectures
- As an introduction, different than most

- A few minutes on the school, you, etc.
- How did programming languages evolve?
  - How did PL research get to where it is today?
- Rough overview of what we will cover
- Next lecture will be refresher on lambda calculus, types, semantics, etc.

A simple plan

- 13 speakers from 10 institutions
- ~26 of you (23 PhD students 2 profs, 1 ugrad)
- Lectures at a PhD-course level
  - More tutorial/class than seminar or conference
  - Wide breadth of topics
  - Less homework and cohesion than a course
  - Not everything will fit everyone perfectly
- Advice
  - Make the most of your time surrounded by great students and speakers
  - Be inquisitive and diligent
  - Have fun

Thanks!

- Jim: none of us would be here without him
- Dan: the co-organizer
- Steering committee
  - Zena Ariola, David Walker, Steve Zdancewic
- Sponsors
  - National Science Foundation
  - ACM SIGPLAN
  - Microsoft Research

A Brief History of PL

Babylon

- Founded roughly 4000 years ago
  - Located near the Euphrates River, 56 mi south of Baghdad, Iraq
- Historically influential in ancient western world
- Cuneiform writing system, written on clay tablets
  - Some of those tablets survive to this day
  - Those from Hammurabi dynasty (1800-1600 BC) include mathematical calculations
    - (Also known for Code of Hammurabi, an early legal code)

A Babylonian Algorithm

A [rectangular] cistern.
The height is 3, 20, and a volume of 27, 46, 40 has been excavated.
The length exceeds the width by 50.
You should take the reciprocal of the height, 3, 20, obtaining 18.
Multiply this by the volume, 27, 46, 40, obtaining 8, 20.
Take half of 50 and square it, obtaining 10, 25.
Add 8, 20, and you get 8, 30, 25
The square root is 2, 55.
Make two copies of this, adding [25] to the one and subtracting from the other.
You find that 3, 20 [i.e., 3 1/3] is the length and 2, 30 [i.e., 2 1/2] is the width.
This is the procedure.

– Donald E. Knuth, *Ancient Babylonian Algorithms*, CACM July 1972

The number n, m represents $n*(60^k) + m*(60^{k-1})$ for some k

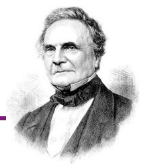
More about Algorithms

- Euclid's Algorithm (Alexandria, Egypt, 300 BC)
  - Appeared in *Elements*
  - Computes gcd of two integers

```
let rec gcd a b =
    if b = 0 then a else gcd b (a mod b)
```

- Al-Khwarizmi (Baghdad, Iraq, 780-850 AD)
  - *Al-Khwarizmi Concerning the Hindu Art of Reckoning*
  - Translated into Latin (in 12th century?)
    - Author's name rendered in Latin as *algoritmi*
    - Thus the word *algorithm*

The Analytical Engine (Babbage)

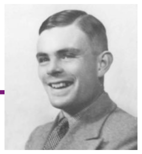


- Charles Babbage (1791-1871, London, England)
  - Developed a mechanical calculator
    - The Difference Engine
  - Like most developers, was overly eager so during 1830's developed plans for the *Analytical Engine*
    - Never completely finished
    - But plans only discovered in 1937
    - Built in 1991 at the Science Museum of London
  - Included branching, looping, arithmetic, and storage
  - Programmed using punch cards

Alonzo Church (1903-1995)

- Mathematician at Princeton Univ.
- Three key contributions:
  - The lambda calculus (lectures in 1936, publ. 1941)
  - Church's Thesis
    - All effective computation is expressed by recursive (decidable) functions
  - Church's Theorem
    - First order logic is undecidable
- The modern start to PL research?
  - What is an algorithm, how do you write it down, and how much can be expressed?

Alan Turing (1912 - 1954)



- The father of modern computer science
  - Dissertation work advised by Church at Princeton
  - Formulated the Turing machine (~1936)
  - A formal definition of a computable algorithm

Early Computers

- ABC (1939-1942)
  - First electronic digital computer
    - As decided by a judge in 1973! (Invalidated ENIAC patent)
- Harvard Mark I (1944)
  - Electronic, used relays
- Z3 (1945)
  - Konrad Zuse, essentially isolated from everyone else
  - Used Plankalkül, a sophisticated programming lang.
    - But no one knew about his results, so not influential
- ENIAC (1946)
  - Electronic Numerical Integrator and Computer

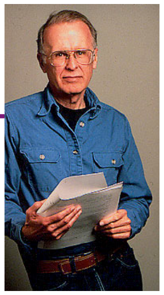
The First Programming Languages

- Early computers could be “programmed” by rewiring them for specific applications
  – Tedious, error prone
- John von Neumann (1903-1957)
  – Three CS contributions (famous for lots of other stuff)
    - von Neumann machine – the way computers are built today
      – A **stored program architecture**
        » Program stored in memory as data, so can be modified
        » Without this, couldn’t easily have prog. langs.
        » Result: Programming in machine code
      – (Unclear that he actually invented this...)
    - “Conditional control transfer” – if and for statements
      – Allows for reusable code, like subroutines
    - Merge sort algorithm

Pseudocodes

- Short Code (1949; John Mauchly)
  – Interpreted instructions
    - E.g., X0 = sqrt(abs(Y0)) becomes 00 X0 03 20 06 Y0
      – 06 = abs, 20 = sqrt, 03 = assignment
  – But needed to translate by hand
- A-0 Compiler (1951; Grace Murray Hopper)
  – Translated symbolic code into machine code
    - Sounds like an assembler...
  – Assigned numbers to routines stored on tape
    - Which would then be retrieved and put in memory
- Are these programming languages?

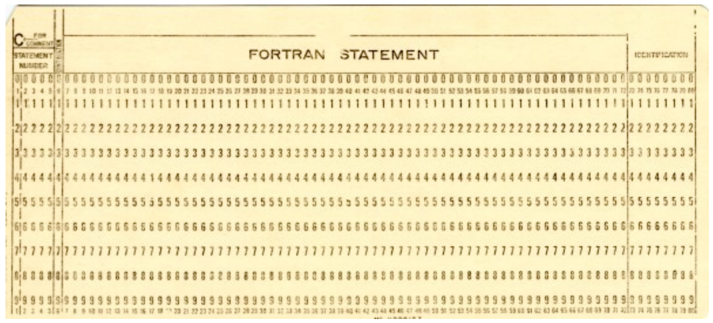
FORTRAN (1954 - 1957)



- FORmula TRANslator
- Developed at IBM by John Backus et al
  – Aimed at scientific computation
  – Computers slow, small, unreliable
    - So FORTRAN needed to produce efficient code
- Features (FORTRAN I)
  – Variable names (up to 6 chars)
  – Loops and Arithmetic Conditionals
    - IF (ICOUNT-1) 100, 200, 300
  – Formatted I/O
  – Subroutines

Writing FORTRAN Programs

- Programs originally entered on punch cards
  – Note bevels on top-left corner for orientation
  – First five columns for comment mark or statement number
  – Each column represents one character
  – Letter: 2 punches: A=12,1 B=12,2 …, Z=0,9



Punch Card Programming

- Not interactive!
  - Feed the deck into the machine
    - Or give it to someone to put in
  - Eventually get back printout with code and output
    - Could take a couple of hours if machine busy
    - Student jobs typically took overnight to run (only to find a syntax error!)
- Long test-debug cycle
  - Debugging by hand critical to not wasting time
    - Don't want to wait several hours to find you made a typo
- What happens if you drop your deck of cards?
  - Could put sequence number in corner for ordering
  - Hard to maintain this as you keep modifying program

Example (FORTRAN 77)

C = "comment"

All-caps

For loop; I goes from 2 to 12 in increments of 1

Cols 1-6 for comment or stmt label

```
C A PROGRAM TO COMPUTE MULTIPLICATION TABLES
      PROGRAM TABLES
      DO 20 I = 2,12
      PRINT *,I,' TIMES TABLE'
      DO 10 J = 1,12
10      PRINT *,I,' TIMES',J,' IS',I*J
20      CONTINUE
      END
```

Source: University of Strathclyde Computer Centre, Glasgow, Scotland

End of program

COBOL (1959)

- COmmon Business Oriented Language
  - Project led by Hopper (again!)
- Design goals
  - Look like simple English (but doesn't read like it!)
  - Easy to use for a broad base
  - Notice: *not* aimed at scientific computing
    - Aimed at business computing instead, very successfully
- Key features
  - Macros
  - Records
  - Long names (up to 30 chars), with hyphen

COBOL Example (Part 1)

Program data (variables)

```
        $ SET SOURCEFORMAT"FREE"
IDENTIFICATION DIVISION.
PROGRAM-ID.  Iteration-If.
AUTHOR.  Michael Coughlan.

DATA DIVISION.
WORKING-STORAGE SECTION.
01  Num1            PIC 9  VALUE ZEROS.
01  Num2            PIC 9  VALUE ZEROS.
01  Result          PIC 99 VALUE ZEROS.
01  Operator        PIC X  VALUE SPACE.
```

Single-digit number

Initial value

Source: http://www.csis.ul.ie/COBOL/examples/conditn/IterIf.htm

Level number; can be used to express hierarchy (records)

Character

The source of Y2K bugs

COBOL Example (Part 2)

```
PROCEDURE DIVISION.        Iteration
Calculator.
    PERFORM 3 TIMES
       DISPLAY "Enter First Number      : " WITH NO ADVANCING
       ACCEPT Num1
       DISPLAY "Enter Second Number     : " WITH NO ADVANCING
       ACCEPT Num2
       DISPLAY "Enter operator (+ or *) : " WITH NO ADVANCING
       ACCEPT Operator
       IF Operator = "+" THEN
          ADD Num1, Num2 GIVING Result
       END-IF
       IF Operator = "*" THEN
          MULTIPLY Num1 BY Num2 GIVING Result
       END-IF
       DISPLAY "Result is = ", Result
    END-PERFORM.
    STOP RUN.
```

COBOL Today

- Was a DoD requirement at one time
  - Important element of its success
- Still used today
  - Legacy mainframe applications
  - New standard in 2002
  - Language has been updated for new features
    - Object-oriented?!
    - Unicode support
    - XML support

Discussion

- FORTRAN and COBOL were very popular
- FORTRAN, in particular, opened up a major research area: compilers!
  - A huge fraction of computer science research through the 70's, at least
  - Loads of well-developed theory and practice
- Both languages still used today
  - Yet PL researchers don't often study them...why not?

LISP (1958)

- LISt Processing
- Developed by John McCarthy at MIT
  - Designed for AI research
- Key ideas:
  - Symbolic expressions instead of numbers
  - Lists, lists, lists
  - Functions, functions, functions
    - Compose simpler functions to form more complex functions
    - Recursion
  - Garbage collection

LISP Code

```
(defun factorial (n)
     (cond ((zerop n) 1)
          (t (times n (factorial (sub1 n)))))
```

- Implemented on IBM 704 machine
  - Machine word was 36 bits
    - Two 15-bit parts, “address” and “decrement,” distinguished
    - car = “Contents of the Address part of Register”
    - cdr = “Contents of the Decrement part of Register”
- Invented maplist function
  - Same as map function in OCaml
- Used lambda notation of Church for functions

LISP Code as Data

- Notice that LISP programs are S-expressions
  - Which represent lists
- So LISP programs can easily manipulate LISP programs
  - Just do list operations to put programs together
  - Probably the first high-level language with this feature

Algol (1958)

- ALGOrithmic Language
  - Designed to be a universal language
  - For scientific computations
- Never that popular, but extremely important
  - Led to Pascal, C, C++, and Java
    - “Algol-like” languages
  - Had formal grammar (Backus-Naur Form or BNF)
  - Algol 60 added block structures for scoping and conditionals
  - Imperative language with recursive functions

Example Code

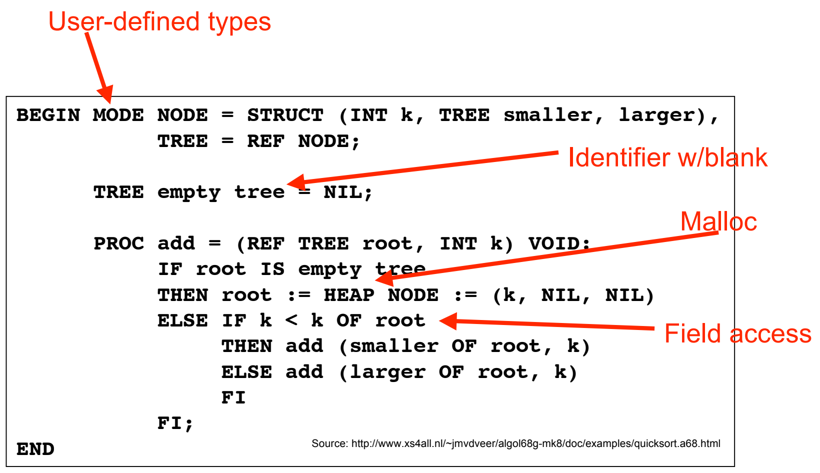
```
procedure Absmax(a) Size:(n, m) Result:(y)
                    Subscripts:(i, k);
    value n, m; array a;
    integer n, m, i, k; real y;
comment The absolute greatest element of the
matrix a, of size n by m is transferred to
y, and the subscripts of this element to i
and k;
begin integer p, q;
    y := 0; i := k := 1;
    for p:=1 step 1 until n do
    for q:=1 step 1 until m do
        if abs(a[p, q]) > y then
            begin y := abs(a[p, q]);
            i := p; k := q
            end
end Absmax
```

Source: http://en.wikipedia.org/wiki/ALGOL

Algol 68

- Successor to Algol 60
  - But bloated and hard to use
  - And very hard to compile
    - E.g., variable names can include blanks!
- Included many important ideas
  - User-defined types
  - Code blocks that return the value of the last expr
  - struct and union
  - parallel processing (in the language)

Example Code



```
BEGIN MODE NODE = STRUCT (INT k, TREE smaller, larger),
           TREE = REF NODE;

      TREE empty tree = NIL;

      PROC add = (REF TREE root, INT k) VOID:
           IF root IS empty tree
           THEN root := HEAP NODE := (k, NIL, NIL)
           ELSE IF k < k OF root
                THEN add (smaller OF root, k)
                ELSE add (larger OF root, k)
                FI
           FI;
END
```

Source: http://www.xs4all.nl/~jmvdveer/algol68g-mk8/doc/examples/quicksort.a68.html

Algol Discussion

- Good points:
  - Standard for writing algorithmic pseudocode
  - First machine-independent language
  - C, C++, Java, etc. all based on it
  - Used BNF to describe language syntax
- Bad points:
  - Never widely used; Some success in Europe
  - Hard to implement
  - FORTRAN much more popular
  - Not supported by IBM

Discussion

- LISP and Algol include many ideas the PL community often thinks of as “good”
  - Why so many in those two languages? Who knows?
- Yet they are not and were not “mainstream”
  - Though descendents C, C++, and Java are

Simula (1965)

- Developed at Norwegian Computing Center
  - By Ole-Johan Dahl and Kristen Nygaard
  - Goal was to simulate complex systems
  - Later used as a general purpose language
- Key features
  - Classes and objects
  - Inheritence and subclassing
  - Pointer to objects
  - Call by reference
  - Garbage collection
  - Concurrency via coroutines

Example

Parameter types

null pointer

Return value

Field access

```
class Point(x,y); real x,y;
  begin
    boolean procedure equals(p); ref(Point) p;
      if p =/= none then
        equals := abs(x - p.x) + abs(y - p.y) < 0.00001
    real procedure distance(p); ref(Point) p;
      if p == none then error else
        distance := sqrt((x - p.x)**2 + (y - p.y)**2);
end ***Point***

p :- new Point(1.0, 2.5);
q :- new Point(2.0, 3.5);
if p.distance(q) > 2 then ...
```

Pointer assignment

Source: http://www.stanford.edu/class/cs242/slides/2004/simula-smalltalk.pdf

Themes

- Languages seem to move from being hardware-oriented to being task-oriented
  - Different languages are good for different things
- Syntax is important
  - Things seem to be getting more uniform
- Languages have been extremely successful
  - We are able to larger, more complex software than ever before

Why Care about PL Research?

(Apologies if I left off your favorite language)

- Sapir-Whorf Hypothesis: Our language influences the thoughts that we can have
  - Not likely true for human languages
  - Definitely not true for programming languages
- But language choice does affect

Ease of programming	Reusability
Maintainability	Performance
Understandability	Correctness

- And...
  - Programming languages are at the heart of CS

What the Heck Does that Title Mean?

Integrating with the External World

- In practice, (many?) programs
  - Are written by people, and thus
    - May have bugs
    - Need to easily express the algorithms we care about
  - Run on hardware
    - Must use certain HW features (I/O, performance chars.)
    - Hardware can fail, either transiently or permanently
  - Need to communicate with other programs
    - Must therefore be secure
    - Must manipulate and communicate a variety of data formats

Analyzing and Debugging Software

- Understanding Multilingual Software [Foster]
  - Parlez vous OCaml?
- Statistical Debugging [Liblit]
  - You are my beta tester, and there's lots of you
- Scalable Defect Detection [Das, Wang, Yang]
  - Microsoft programs have no bugs

Programming Models

- Types for Safe C-Level Programming [Grossman]
  - C without the ick factor
- Staged Programming [Taha]
  - Programs that produce programs that produce programs...
- Prog. Models for Dist. Comp. [Smaragdakis]
  - We've secretly replaced your centralized program with a distributed application. Can you tell the difference?

The Web

- Web and Database Application Security [Su]
  - How not to be pwn3d by 1337 haxxors
- XML and Web App. Programming [Møller]
  - X is worth 8 points in Scrabble...let's use it a lot

Other Really Important Stuff

- Fault Tolerant Computing [August, Reis]
  - Help, I’ve been hit by a cosmic ray!
- Typing Ad Hoc Data [Fisher]
  - Data, data, everywhere, but what does it mean?