Introduction to Design Languages

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Last Time

- Introduction to the class
- Embedded systems
- Role of languages: shape solutions
- Project proposals due September 26
  - Do you know what you're doing?

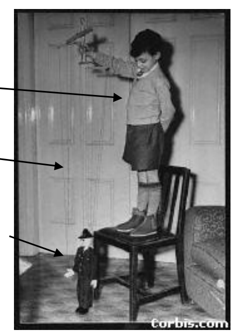
Lobby, Paris Opera House

This Time

- General ideas behind languages
- Syntax, Semantics, and Models of Computation
- Specification versus Modeling
- Concurrency: Two things at once
- Nondeterminsm: Unpredictability
- Types of communication: Memory, broadcasting
- Hierarchy

Syntax, Semantics, and Model

- Marionette model
- You control the syntax
- The semantics connect the syntax to the model
- You ultimately affect a model



Syntax

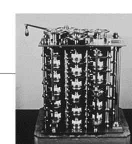
Rosetta stone

- Formally:

  Language: infinite set of strings from an alphabet

	Alphabet
DNA	{A T G C}
Student Transcripts	{w1007-02 w1009-01 w4559-02 …}
English	{aardvark abacus abalone …}
Verilog	{always module …}

Computational Model

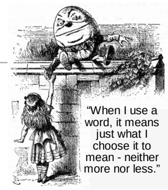


Babbage's Difference Engine

- What a string ultimately affects
- Does not need to be unique

	Model
DNA	Proteins suspended in water
Student Transcripts	Your knowledge The admiration of others
English	Natural language understanding
Verilog	Discrete event simulator Netlist of gates and flip-flops

Semantics



- How to interpret strings in the model
- Also not necessarily unique

	Semantics
• DNA	[[AGA]] = Arginine [[TAG]] = STOP
• Student Transcripts	[[w1007-02]] = Java
• English	[[Look out!]] = I'm in danger
• Verilog	[[always @posedge clk]] = FF

Defining Syntax

- Generally done with a grammar
- Recursively-defined rules for constructing valid sentences
- "Backus-Naur Form"

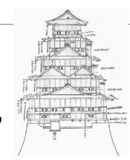
***expr* ::**
    literal
    | *expr + expr*
    | *expr * expr*

- Not a focus of this class

Defining Semantics

- Operational Semantics
  - Abstract machine (memory, program counter)
  - Each statement advance machine state
  - Closest to implementation
- Denotational Semantics
  - Context domain (memory state)
  - Answer domain (result, I/O behavior)
  - Meaning function: Program $\rightarrow$ (Context $\rightarrow$ Answer)
  - Much more mathematical
  - Able to deal with recursion and self-reference

Specification and Modeling



- How do you want to use the program?
- Specification languages say "build this, please"
- Modeling languages allow you to describe something that does or will exist
- Distinction a function of the model and the language's semantics

Copernican Model of the Solar System

Specification Versus Modeling

- C is a specification language
  - Semantics very operational
  - Clear how the language is to be translated into assembly language
- Verilog is a modeling language
  - Semantics suggestive of a simulation procedure
  - Good for building a model that captures digital hardware behavior (delays, race conditions, unknown values)
  - Not as good for specification: how do you build something with a specific delay?

Gratuitous Picture

- Chartres Cathedral, France
- Façade a renovation of and earlier Romanesque church (note rounded windows)
- Right tower considered the architectural gem
  - Starts complicated
  - Ends simple, to-the-point

Concurrency

- Why bother?
- Harder model to program
- Real world is concurrent
- Good controller architecture: concurrently-running process controlling each independent system component
- E.g., process for right brake, process for left brake, process for brake pedal

The Challenge of Concurrency

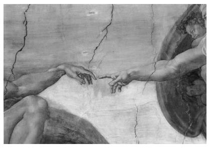
- Synchronization
- How to arbitrate access to shared resources
  - Memory
  - I/O ports
  - Actuators
- Different approaches to concurrency a focus of the course

Approaches to Concurrency

- Shared memory / "Every man for himself"
  - Adopted by Java, other software languages
  - Everything's shared, nothing synchronized by default
  - Synchronization through locks/monitors/semaphores
  - Most flexible
  - Easy to get wrong
- Synchronous
  - Global clock regulates passage of time
  - Very robust in the presence of timing uncertainty
  - Proven very successful for hardware design
  - Synchronization overhead often onerous

Communication and Concurrency

- Idea: let processes run asynchronously and only force them to synchronize when they communicate
- CAR Hoare's Communicating Sequential Processes
  - Rendezvous-style communication:
  - Processes that wish to communicate both wait until the other is ready to send/receive



- Kahn Process Networks (later in the course)
  - Communicate through channels
  - Writer always continues
  - Reader waits until data has arrived

Nondeterminism

- Does a program mean exactly one thing?
- Example from C:

"Increment a, return result"

printf("%d %d %d", ++a, ++a, ++a);

- Argument evaluation order is undefined
- Program behavior subject to compiler interpretation
- Are you sure your program does what you think?

Nondeterministic Is Not Random

- Deterministic: 1+1 = 2 *always*
- Random: 1+1 = 2 *50% of the time,* 3 *otherwise*
- Nondeterministic: 1+1 = 2 *or* 3, but I'm not telling
- The nondeterministic behavior could look determinstic, random, or something worse

Nondeterminism Is Awful

- Much harder to be sure your specification or model is correct
- True nondeterminstic language difficult to simulate
  - Should produce "any of these" results
  - Must maintain all possible outcomes, which grows exponentially
- Idiosyncrasies of a particular implementation of a nondeterministic language often become the de facto standard

Example From Verilog

- Concurrent procedure execution order undefined

always @(posedge clk) $write("a")

always @(posedge clk) $write("b")

- First implementation moved procedures between two push-down stacks. Result:

a b b a a b b a a b b a

Later simulators had to match now-expected behavior

Nondeterminism Is Great

- True nondeterministic specification often exponentially smaller than deterministic counterpart
- Implicit "all possible states" representation
- E.g., nondeterministic finite automata for matching regular expressions
- If system itself is truly nondeterministic, shouldn't its model also be?
- Can be used to expose design errors
- More flexible: only there if you want to use it
- Correctness remains more elusive

Communication

- Memory
  - Value written to location
  - Value stays until written again
  - Value can be read zero or more times after write
  - No synchronization

- Buffer
  - Value written to buffer
  - Value held until read
  - Values read back in order they were written

Communication

- Wires
  - May or may not have explicit write operation
  - Value immediately seen by all readers
  - More like a system of equations than a sequence of operations

Hierarchy

- Most languages have ability to create pieces and assemble them
- Advantage: Information hiding
  - User does not know details of a piece
  - Easier to change implementation of piece without breaking whole system
  - Easier to get small piece right
  - Facilitates abstraction: easier to understand the whole
- Advantage: Reuse
  - Pieces less application-specific; can be used elsewhere

Summary

- Languages have syntax, semantics, and model
- Syntax usually defined with grammar
- Semantics can be defined operationally or denotationally
- Many possible models: A focus of this class

- You ask for something with a specification language
- You describe something that does or will exist with a modeling language

Summary

- Concurrency useful for handling real world
- Synchronization big challenge
  - Shared memory and locks
  - Synchrony
  - Rendezvous synchronization
  - Buffer synchronization

- Nondeterminism
  - Good for certain models
  - Can be very succinct
  - Makes specification hard
  - Makes verification harder

Summary

- Communication techniques
  - Memory
  - Buffered
  - Wired

- Hierarchy for information hiding