CS 4110

Victory Lap

Schedule

Date	Topic	Notes	Assignments
August 24	Course Overview	slides	
August 26	Introduction to Semantics	slides notes	
August 29	Inductive Definitions and Proofs	slides notes	
August 31	Inductive Proof and Large-Step Semantics	slides notes	A1 out
September 2	The IMP Language	slides notes	
September 5	**No class (Labor Day)**		
September 7	IMP Properties	slides notes scribbles	A1 due; A2 out
September 9	Denotational Semantics	slides notes	
September 12	Denotational Semantics Examples	slides notes slides+ scribbles	
September 14	Axiomatic Semantics	slides notes	A2 due; A3 out
September 16	Hoare Logic	slides notes scribbles	
September 19	Hoare Logic Examples	slides notes scribbles	
September 21	Weakest Preconditions	slides notes	A3 due; A4 out
September 23	Lambda Calculus	notes scribbles	
September 26	More Lambda Calculus and Substitution	slides notes	
September 28	Lambda Calculus Encodings	slides notes slides+	A4 due
September 30	Programming in the Lambda Calculus	slides notes	
October 3	Definitional Translation and Continuations	slides notes	
October 5	**Preliminary Exam I**		
October 7	Exam Debrief		
October 10	**No class (Fall Break)**		
October 12	Simple Types	notes scribbles	A5 out
October 14	Proving Type Soundness	slides notes scribbles	
October 17	Normalization	slides notes slides+ scribbles	
October 19	Advanced Types	slides notes	A5 due; A6 out
October 21	Polymorphism	slides notes	
October 24	**Guest lecture: Yaron Minsky, Jane Street. "GADTs for Speed Demons"**		
October 26	Type Inference	slides notes slides+	A6 due; A7 out
October 28	Compiling with Continuations	slides notes slides+	
October 31	Records and Subtyping	slides notes slides+	
November 2	Existential Types	slides notes	A7 due; A8 out
November 4	Recursive Types	slides notes	
November 7	Propositions as Types	slides notes	
November 9	Featherweight Java	slides notes slides+	A8 due
November 11	Featherweight Java Properties	slides notes slides+ scribbles	
November 14	Concurrency and Parallelism	slides code	
November 16	**Preliminary Exam II**		
November 18	Exam Debrief		
November 21	Shared-Memory Parallelism	slides code	
November 23	**No class (Thanksgiving)**		
November 25	**No class (Thanksgiving)**		
November 28	Probabilistic Programming	slides notes code	A9 out
November 30	Approximate Computing	slides paper	

Mathematical foundations & inductive definitions

$$
\begin{aligned}
e ::= {} & x \\
\mid {} & n \\
\mid {} & e_1 + e_2 \\
\mid {} & e_1 * e_2 \\
\mid {} & x := e_1 \,;\, e_2
\end{aligned}
$$

$$
\frac{p = m + n}{\langle \sigma, n + m \rangle \longrightarrow \langle \sigma, p \rangle}\ \text{Add}
$$

Operational semantics & IMP

$$\frac{\langle \sigma, e_1 \rangle \Downarrow n_1 \qquad \langle \sigma, e_2 \rangle \Downarrow n_2 \qquad n = n_1 + n_2}{\langle \sigma, e_1 + e_2 \rangle \Downarrow n}$$

$$\frac{\langle \sigma, e_1 \rangle \Downarrow n_1 \qquad \langle \sigma, e_2 \rangle \Downarrow n_2 \qquad n = n_1 \times n_2}{\langle \sigma, e_1 \times e_2 \rangle \Downarrow n}$$

Denotational semantics

Exercise 2. A simple way to prove two programs equivalent is to show that they denote the same mathematical object. In particular, this is often dramatically simpler than reasoning using the operational semantics. Using the denotational semantics, prove the following equivalences:

(a) $(x := x + 21; x := x + 21) \sim x := x + 42$

(b) $(x := 1;$ **do** $x := x + 1$ **until** $x < 0) \sim ($**while true do** $c)$
for all commands c.

(c) $(x := x) \sim ($**if** $(x = x + 1)$ **then** $x := 0)$

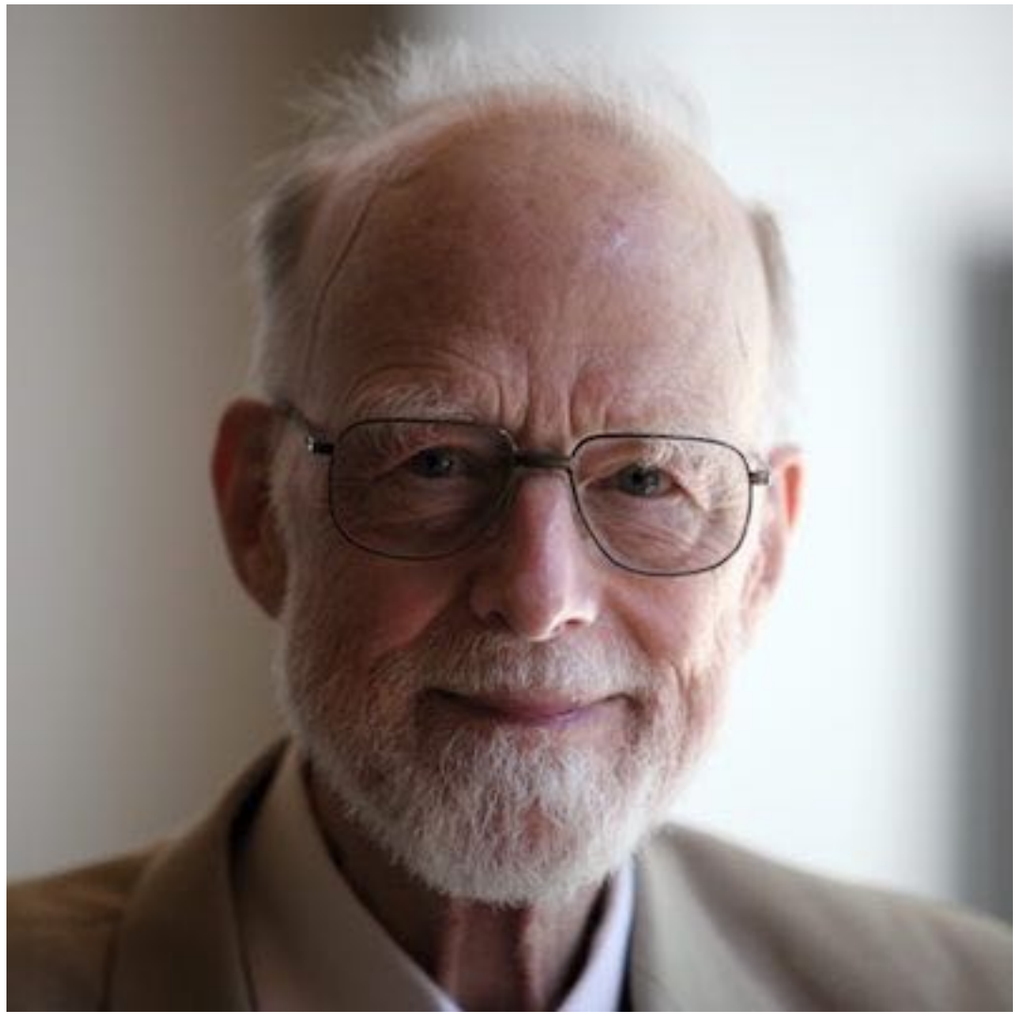
Axiomatic semantics & Hoare logic

$\{\mathsf{x} = n \wedge n > 0\} \Rightarrow$
$\{1 = 1 \wedge \mathsf{x} = n \wedge n > 0\}$
$\mathsf{y} := 1;$
$\{\mathsf{y} = 1 \wedge \mathsf{x} = n \wedge n > 0\} \Rightarrow$
$\{\mathsf{y} * \mathsf{x}! = n! \wedge x \geq 0\}$
while $\mathsf{x} > 0$ **do** $\{$
$\quad \{\mathsf{y} * \mathsf{x}! = n! \wedge x > 0 \wedge x \geq 0\} \Rightarrow$
$\quad \{\mathsf{y} * \mathsf{x} * (\mathsf{x} - 1)! = n! \wedge (x - 1) \geq 0\}$
$\quad \mathsf{y} := \mathsf{y} * \mathsf{x};$
$\quad \{\mathsf{y} * (\mathsf{x} - 1)! = n! \wedge (x - 1) \geq 0\}$
$\quad \mathsf{x} := \mathsf{x} - 1$
$\quad \{\mathsf{y} * \mathsf{x}! = n! \wedge x \geq 0\}$
$\}$
$\{\mathsf{y} * \mathsf{x}! = n! \wedge (x \geq 0) \wedge \neg(x > 0)\} \Rightarrow$
$\{\mathsf{y} = n!\}$

Axiomatic semantics & Hoare logic

Kurt Gödel

vs.



Tony Hoare

λ-calculus!!!!!!!!!!!!!!!!!!1

$$\frac{}{(\lambda x.\, e)\, v \to e\{v/x\}}\ \beta$$

Types

Simple!

Algebraic!

Polymorphic!

Existential!

Inference!

Subtyping!

Advanced topics

this can never happen

Along the way…

Finished 8 (maybe 9) homework assignments, ranging from difficult to extremely difficult

Asked 421 questions on Piazza

Showed up to lecture at 9am every single time

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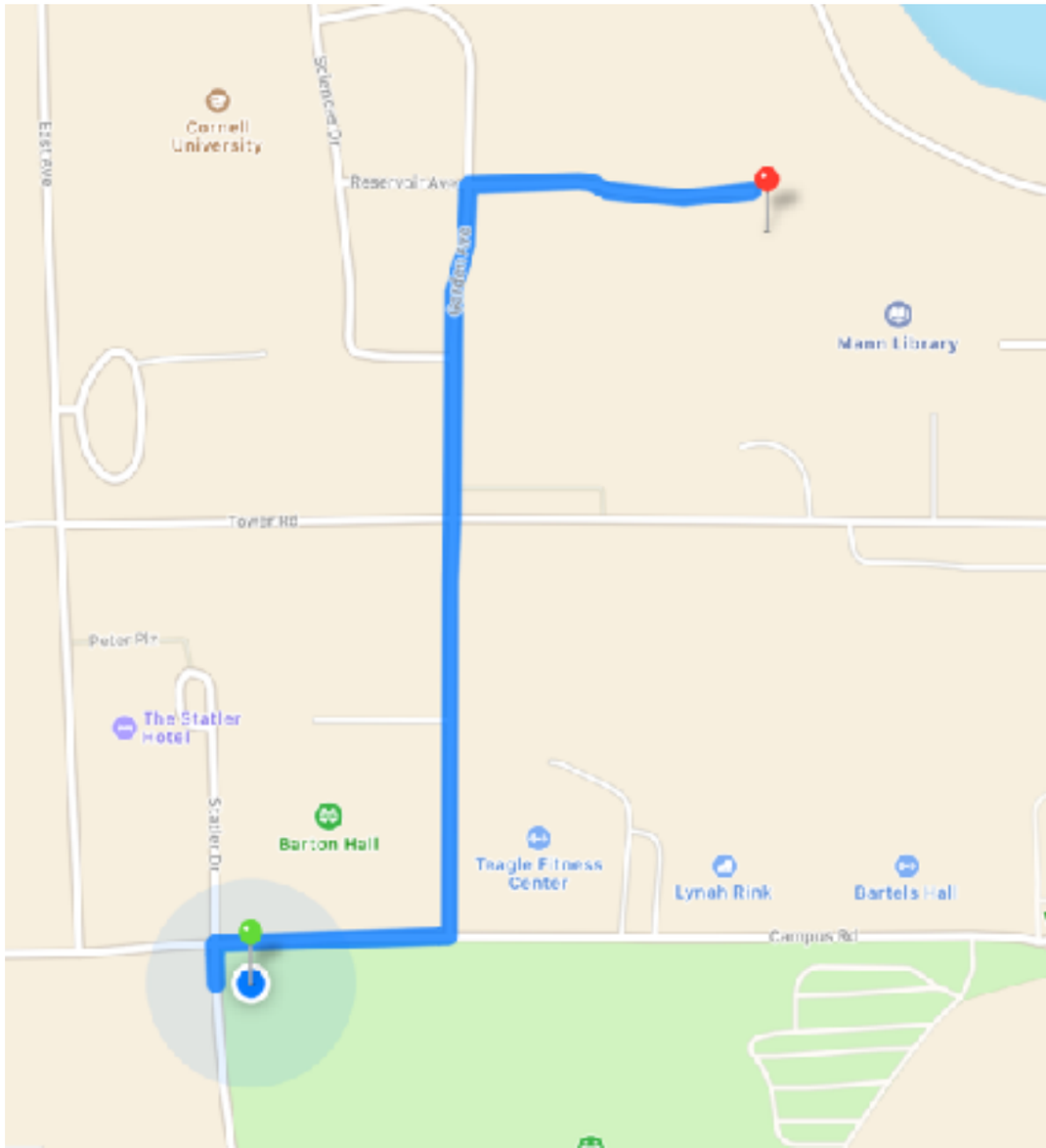
The final

Saturday, December 10 at 2:00pm

Warren B25

Practice problems on CMS now



There's more…

Compilers, JITs, garbage collection…

Language-level security, privacy…

Proof assistants, automated theorem proving…

Program synthesis, sketching, superoptimization…

Bug finding, static analysis, dynamic analysis…

Domain-specific languages, programming for GPUs…

Next steps?

CS 6110: Advanced Programming Languages

CS 7190: PL Seminar

CS 4999: Independent Research

TA for 4110 next time

Thank you!

Keep in touch.