Programming Languages and Compilers (CS 421)

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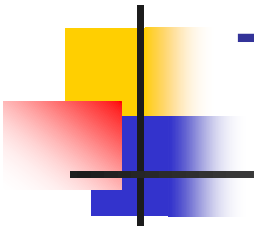
http://courses.engr.illinois.edu/cs421/

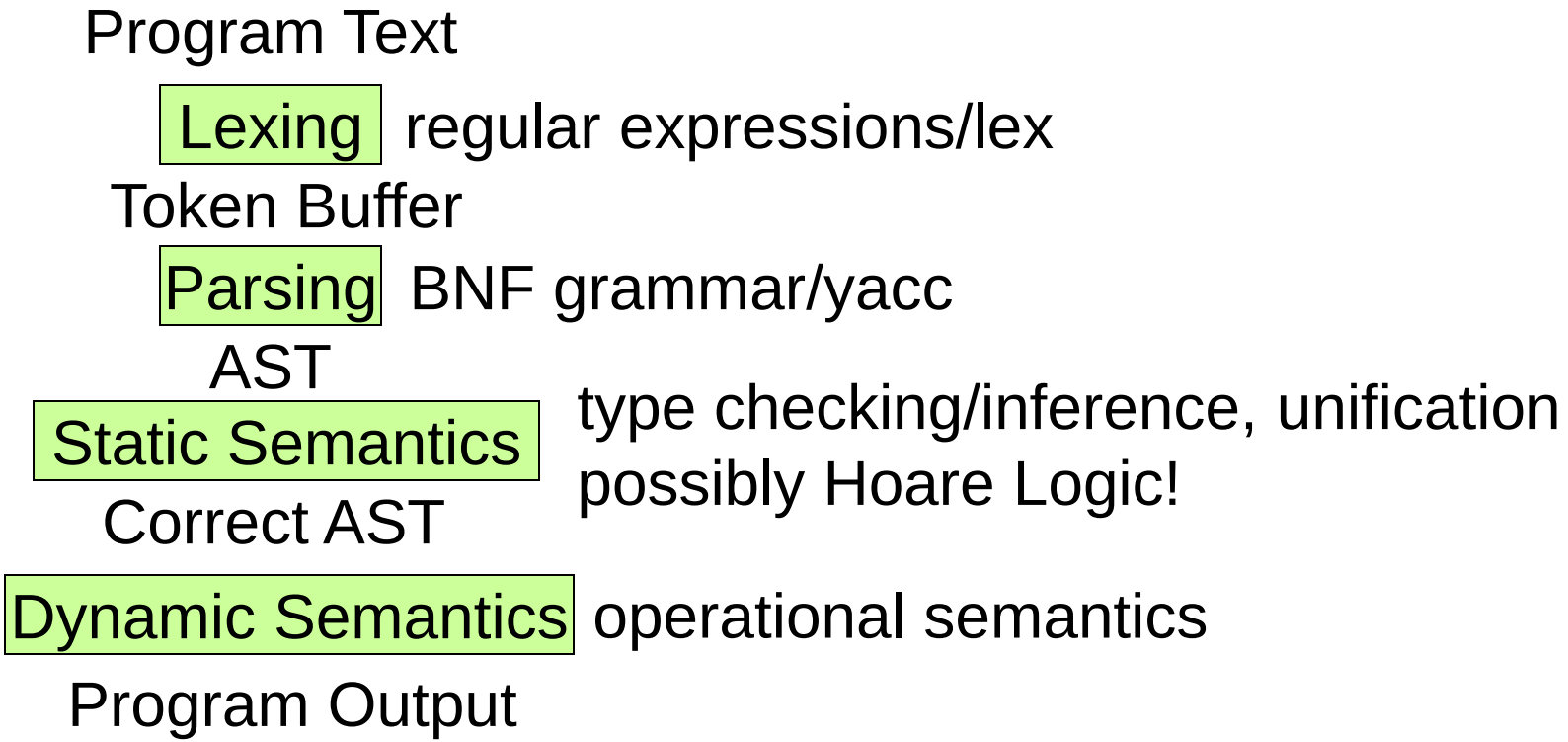
Based in part on slides by Mattox Beckman, as updated by Vikram Adve, Gul Agha, Elsa Gunter, and Dennis Griffith



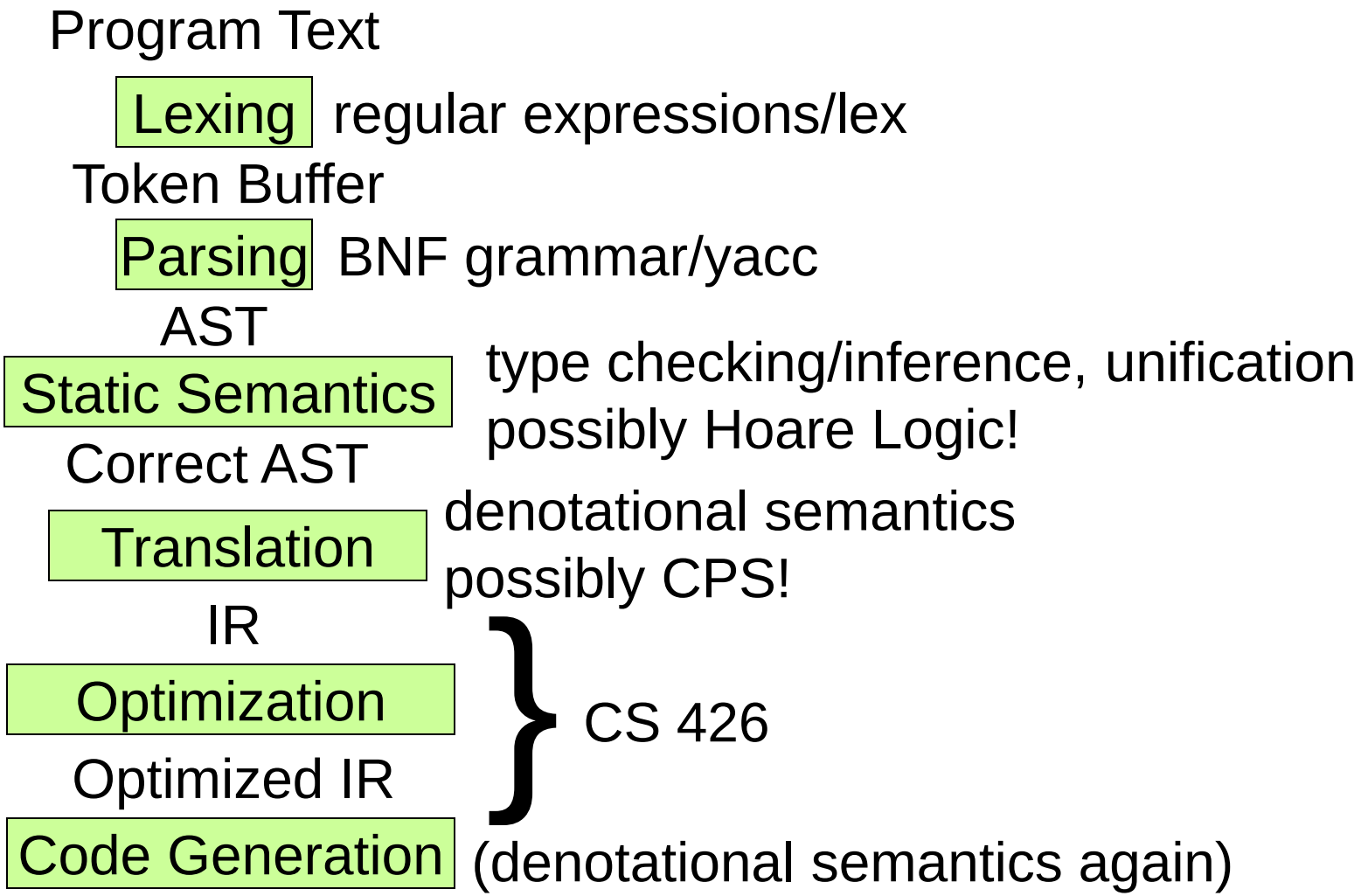
The Big Picture

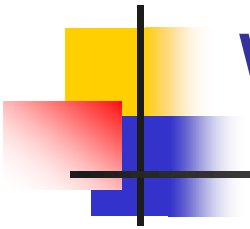
- OCaml/Functional Programming
- Continuation Passing Style
- Type checking/inference
- Unification
- Lexing
- Parsing
- Operational Semantics
- Lambda Calculus
- Hoare Logic

Anatomy of an Interpreter



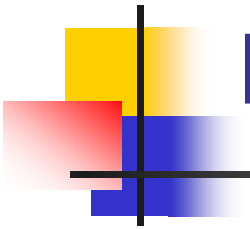
Anatomy of a Compiler





What can we do now?

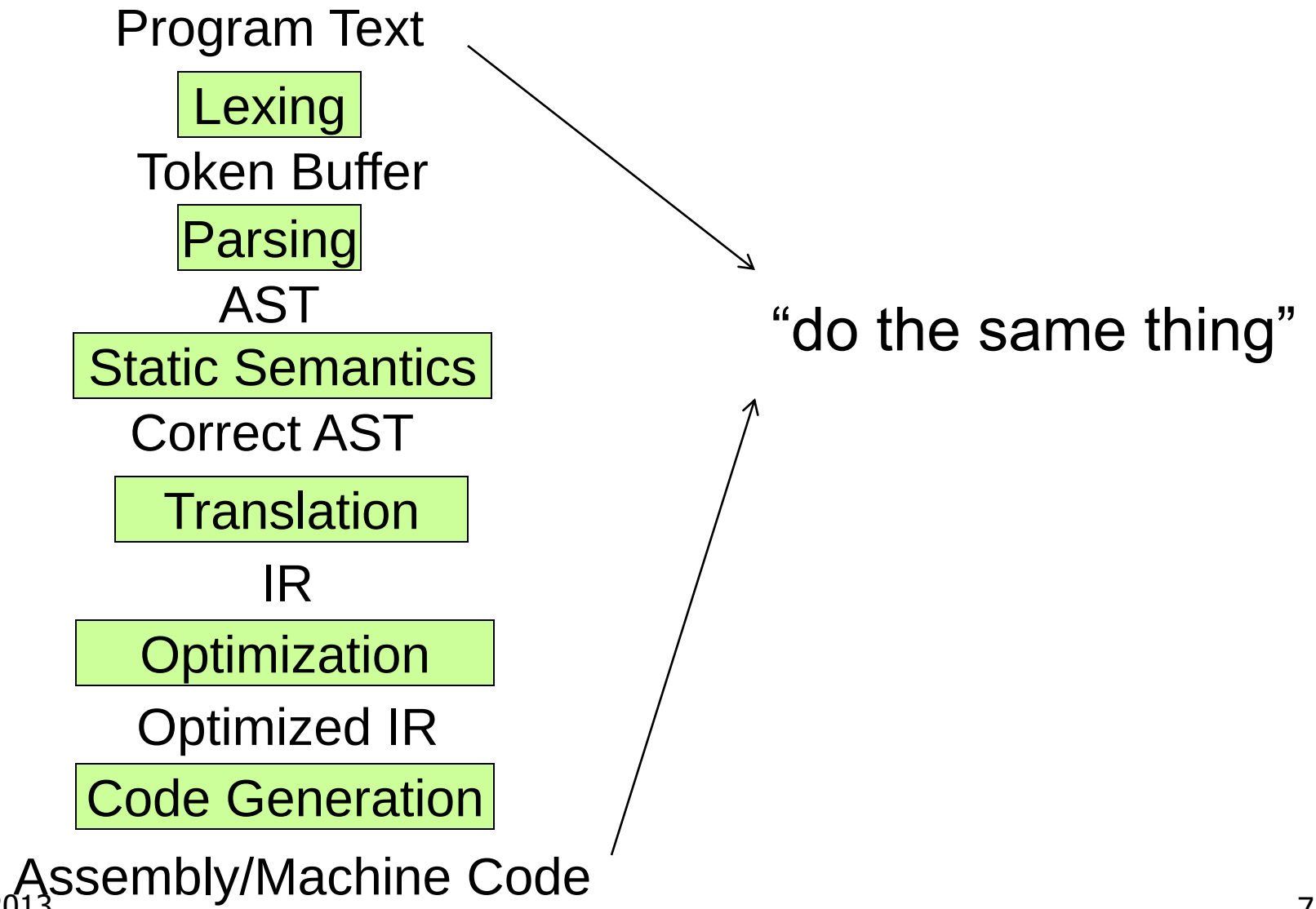
- Write functional programs (which parallelize well and compute math quickly)
- Build compilers and interpreters
- Specify and implement programming languages
- Prove programs correct
- Compare various approaches to PL syntax and semantics



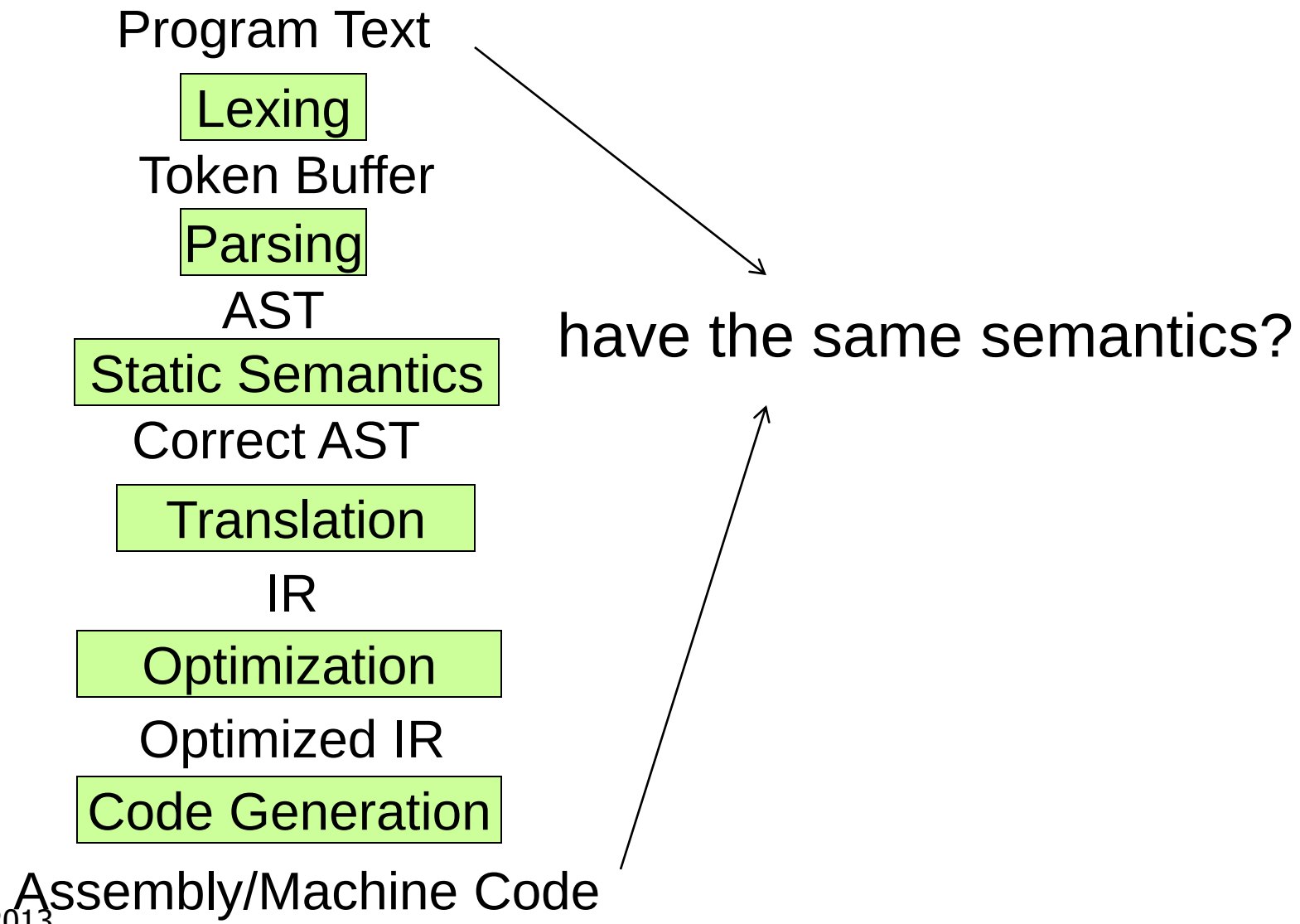
Formal Methods

- The study of proving programs correct
- But what is a program?
  - Anything we can model formally/mathematically
  - Computer programs, machines, workflows
  - Compilers, air traffic control protocols, security protocols, simulators, Java programs
- And how do we prove it correct?
  - Syntax, semantics, formal logic, automatic/interactive provers

Verifying a Compiler



Verifying a Compiler



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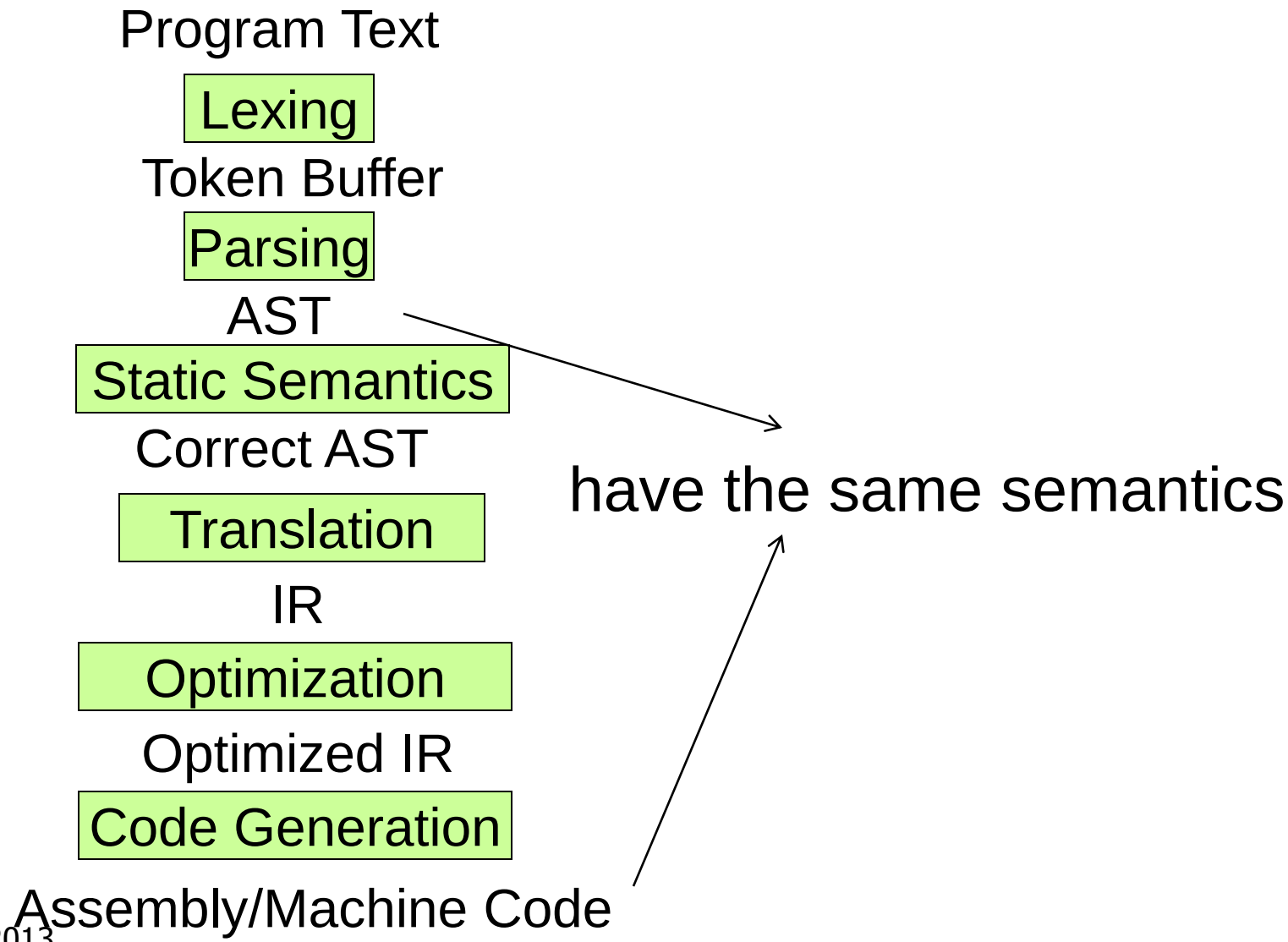

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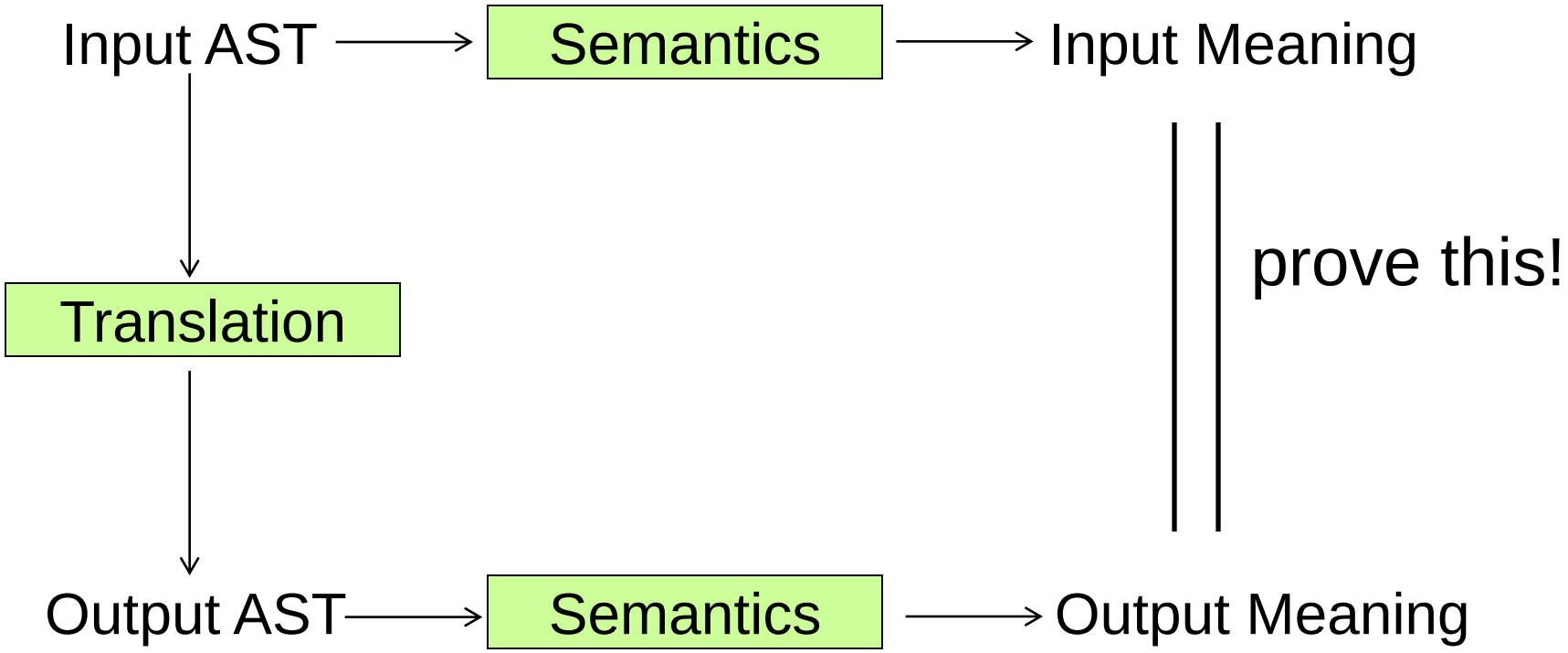
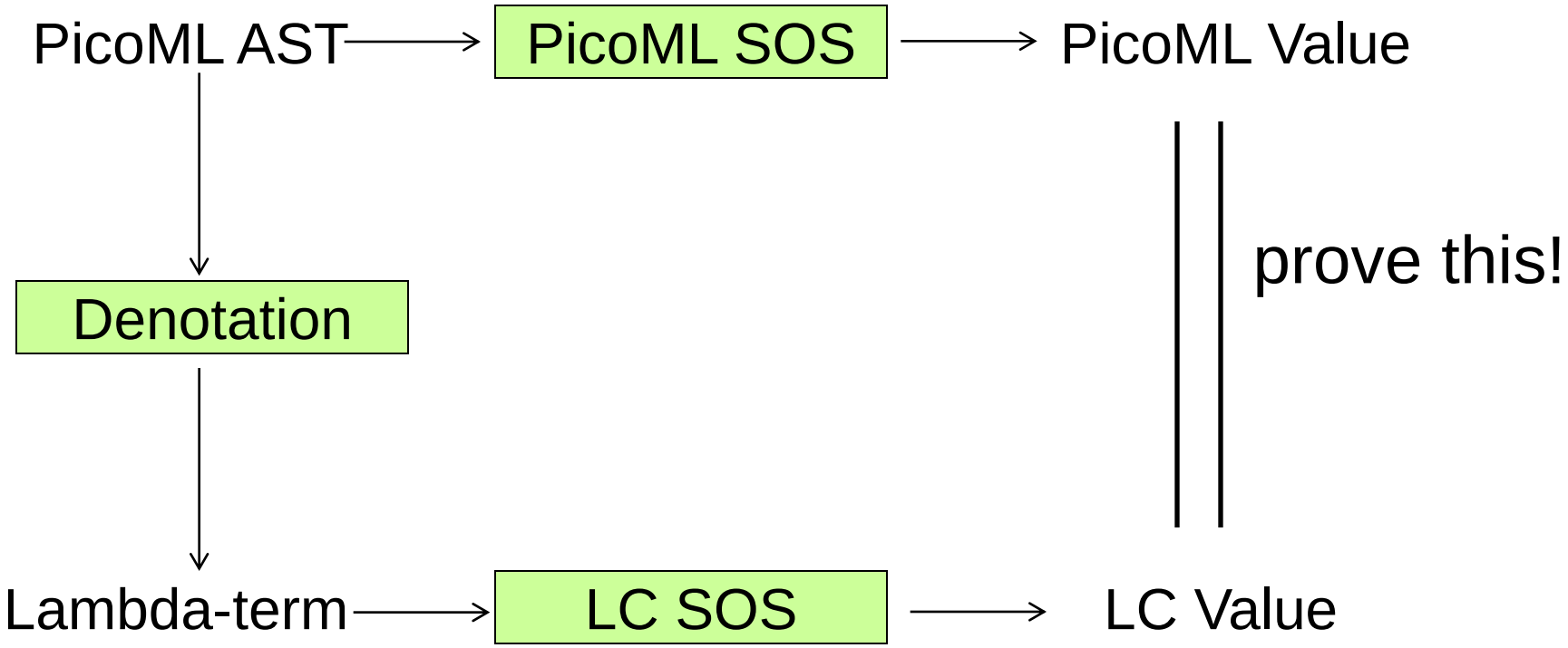
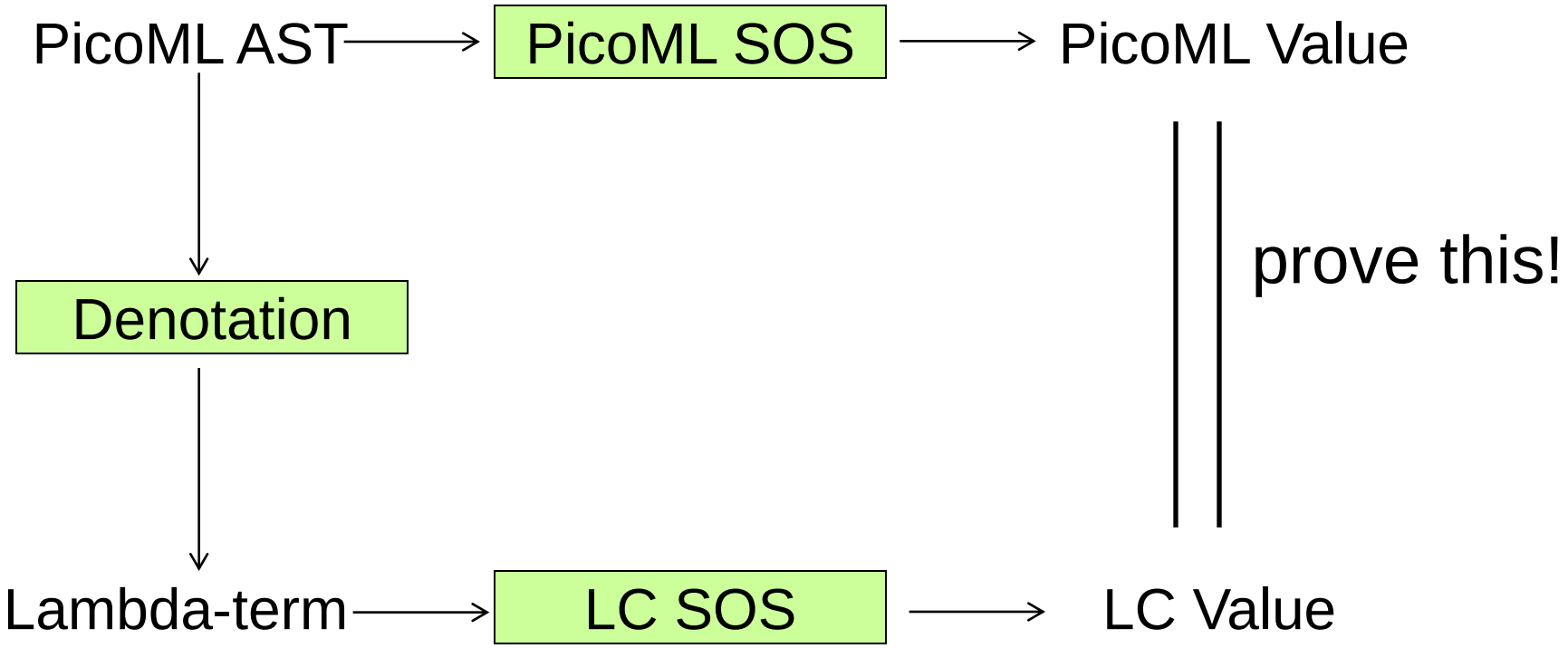


Verifying a Compiler – Example

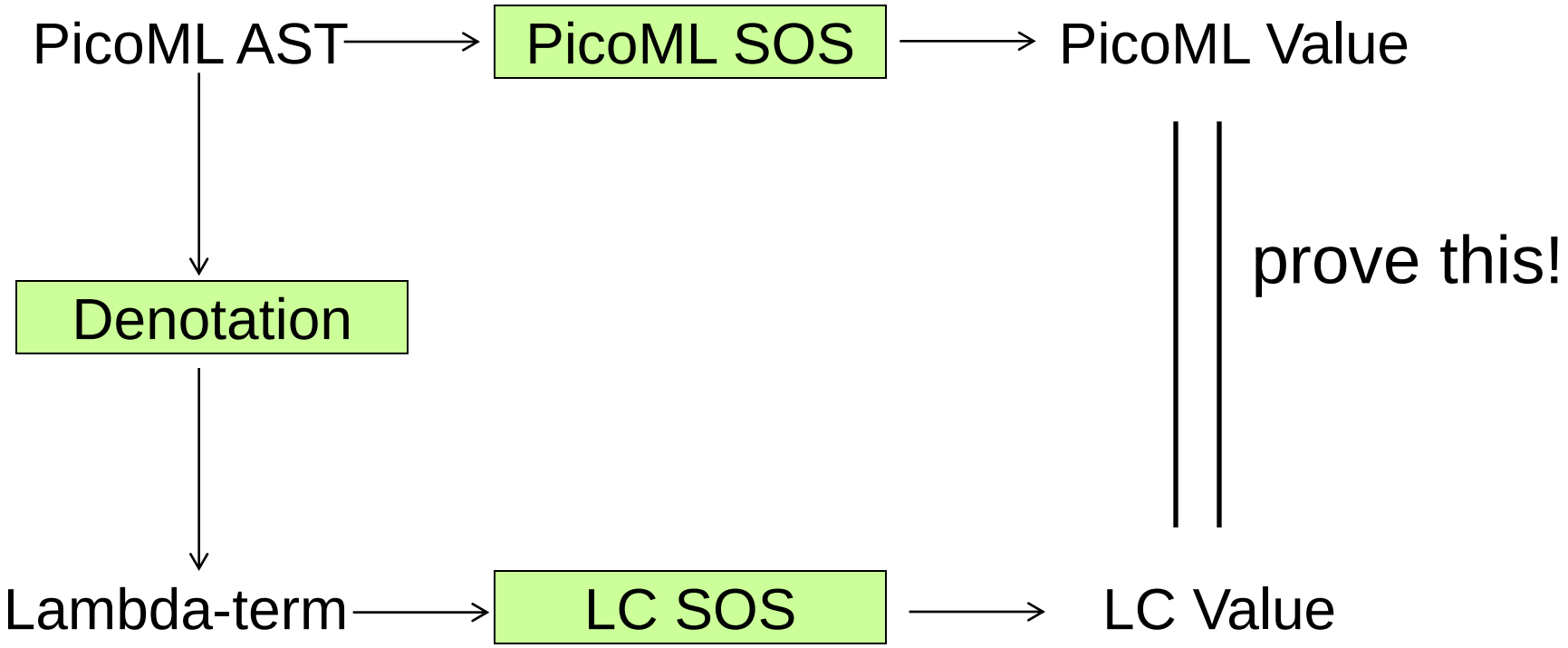


Verifying a Compiler – Example



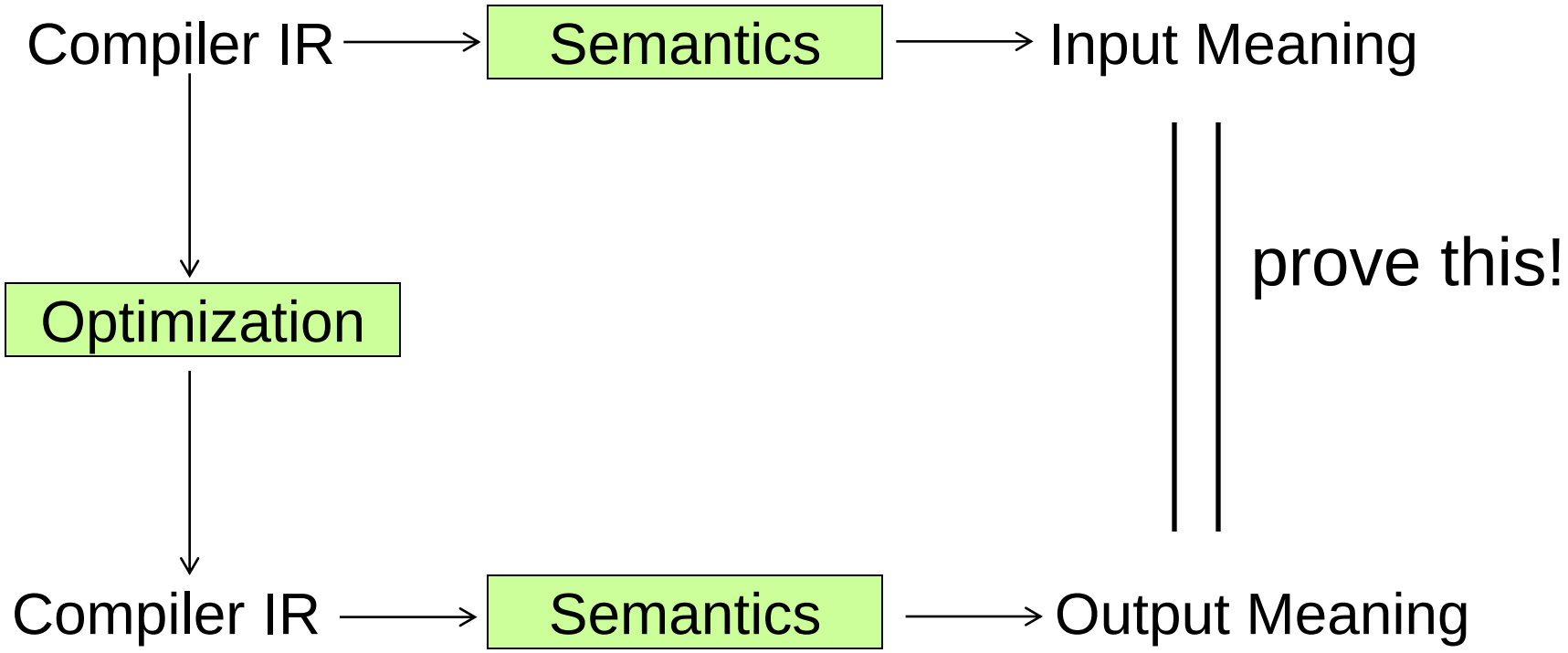
Can we prove this for *every program*?

Verifying a Compiler – Example

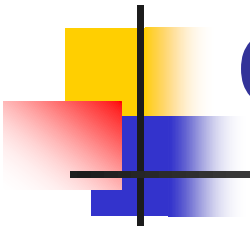


Can we prove this for *every program*? Yes.

Verifying a Compiler – Harder Case



Can we prove this for *every program*?

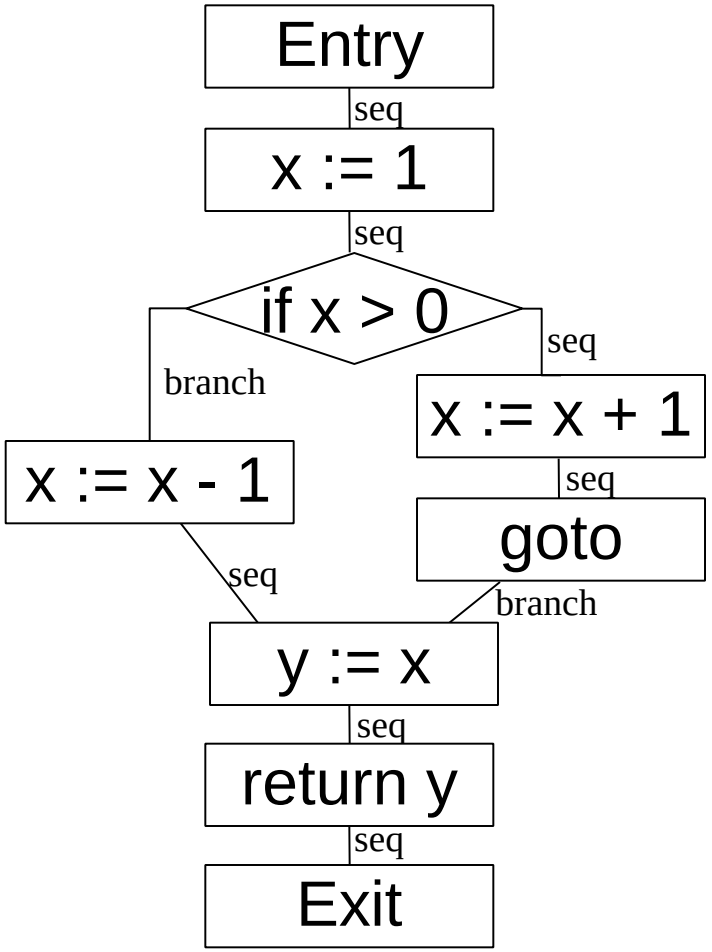


Control Flow Graphs

- ASTs are good for complex expressions
- What if we care more about control flow than expression structure?
- Graphs with commands on nodes, edges showing control flow

Control Flow Graphs

```
0:  x := 1
1:  if x > 0 goto 4
2:  x := x + 1
3:  goto 5
4:  x := x - 1
5:  y := x
6:  return y
```



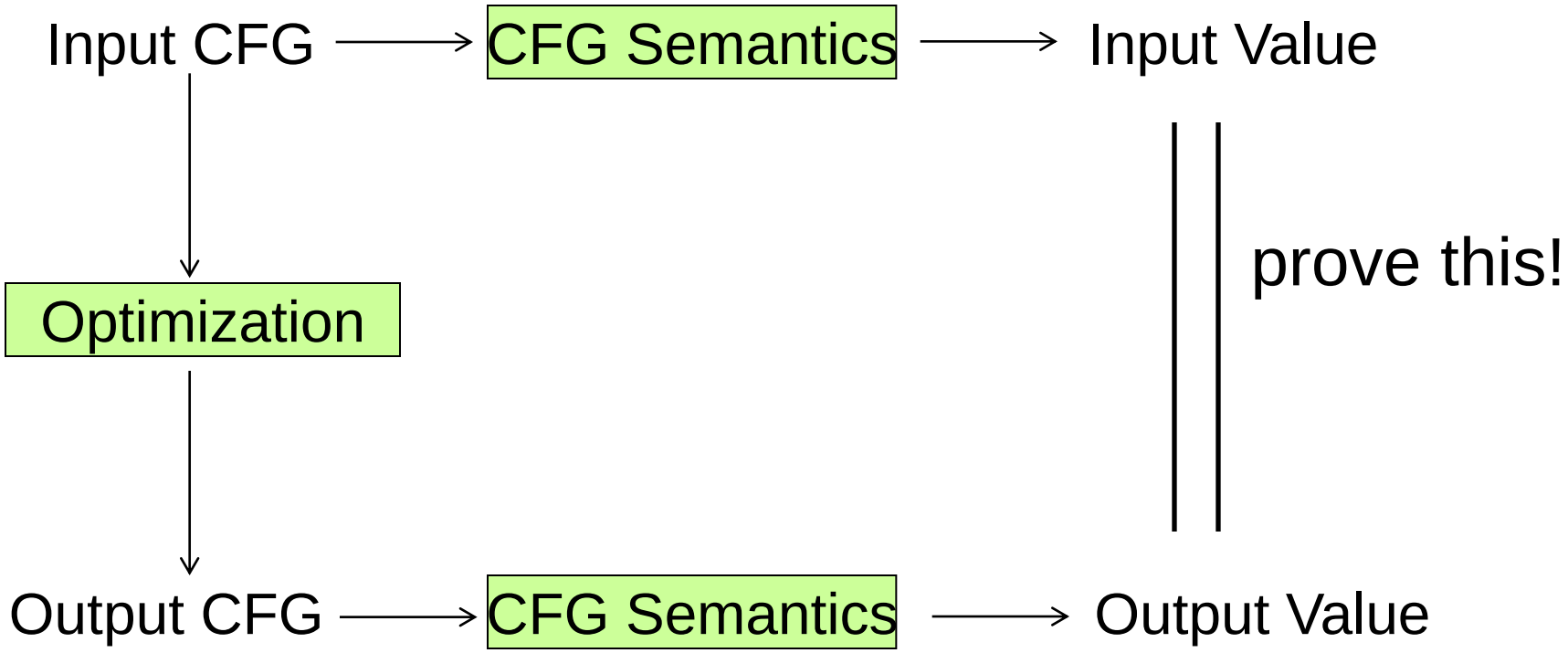
Semantics on Control Flow Graphs

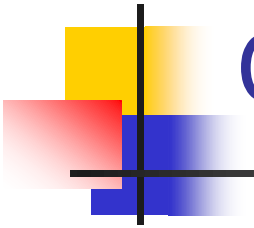
- Configurations are (G, n, m), where G is a graph and n is the currently executing node
- Small-step for moving between nodes, big-step within a single node

- E.g. (Assignment Rule):

$$\frac{\text{label}(G, n) = I := E \qquad (E, m) \Downarrow v \qquad \text{out}(n) = n'}{(G, n, m) \rightarrow (G, n', m[x \leftarrow v])}$$

Verifying a Compiler – Harder Case





Questions?