# *COS320: Compiling Techniques*

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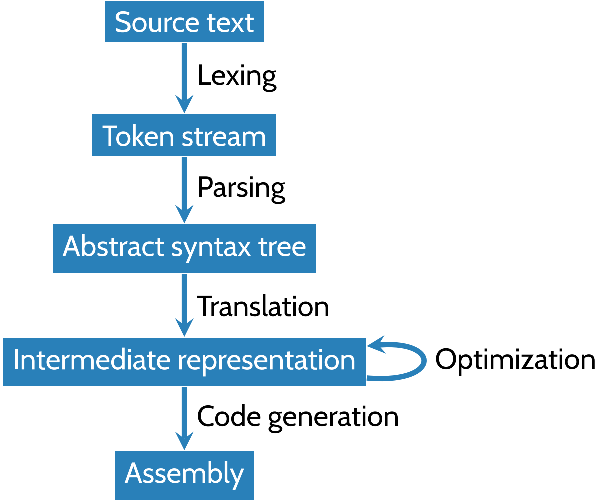
# Compiler phases (simplified)



# Last time: let-based IR

Each instruction has at most three operands (“three-address code”)

```
  <instr> ::= let <uid> = <operand> <op> <operand>;      Instructions
            | load <uid> = <var>;
            | store <var> = <operand>;
            | return <operand>;
<operand> ::= <uid> | <integer>                          Operands
     <op> ::= + | *                                      Operations
```

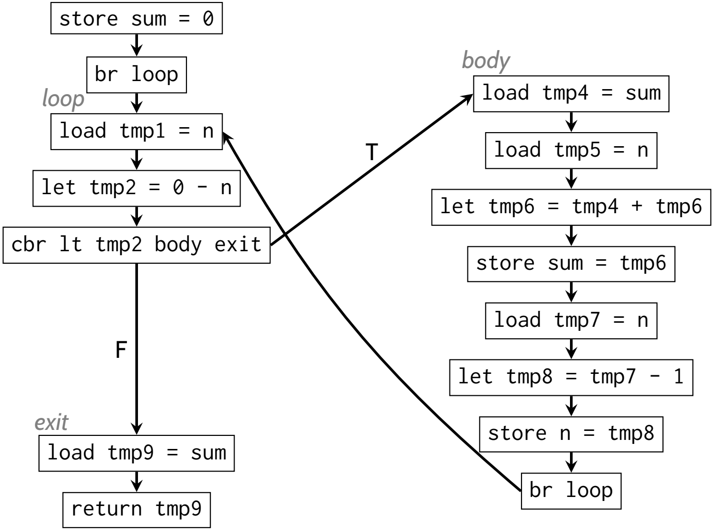
# *Control Flow*

# Concrete syntax

| | |
|---|---|
| <instr> := let <uid> = <operand> <op> <operand>; | Instructions |
| \| load <uid> = <var>; | |
| \| store <var> = <operand>; | |
| <operand> := <uid> \| <integer> | Operands |
| <op> := + \| * | Operations |
| <terminator> ::= br <label> | Branch |
| \| cbr <cc> <operand> <label> <label> | Conditional branch |
| \| return <operand> | Return |
| <cc> ::= EqZ \| LeZ \| LtZ | |
| <block> ::= <instr><block> \| <terminator> | |
| <program> ::= <program><label>: <block> \| <block> | |

# Control Flow Graphs (CFG)

```
int sum_upto(int n) {
  int sum = 0;
  while (n > 0) {
    sum += n;
    n--;
  }
  return sum;
}
```



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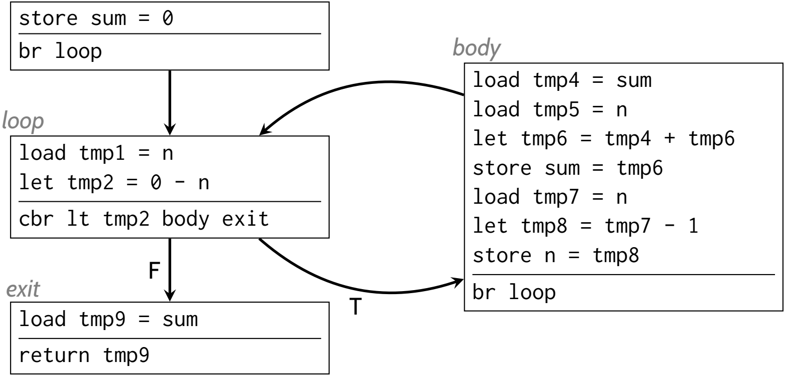

- Control flow graphs are a graphical representation of the control flow through a procedure
- A *basic block* is a sequence of instructions that
  1. Starts with an *entry*, which is named by a label
  2. Ends with a control-flow instruction (`br`, `cbr`, or `return`)
     - the *terminator* of the basic block
  3. Contains no interior labels or control flow instructions
- A *control flow graph* (CFG) for a procedure $P$ is a directed, rooted graph where
  - The nodes are basic blocks of $P$
  - There is an edge $BB_i \to BB_j$ iff $BB_j$ may execute immediately after $BB_i$
  - There is a distinguished entry block where the excution of the procedure begins

- CFG models all program executions
  - Every execution corresponds to a path in the CFG, starting at entry
    - Path = sequence of basic blocks $B_1, \ldots, B_n$ such that for each $i$, there is an edge from $B_i$ to $B_{i+1}$
    - *Simple* path = path without repeated basic blocks
  - (But not vice-versa!)

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  - (But not vice-versa!)
- Graph structure used extensively in optimization (data flow analysis, loop recognition, ...)
- Simple application: dead code elimination
  1. Depth-first traversal of the CFG
  2. Any *unvisited node* is removed

# Why basic blocks?

- Control flow graphs may be defined at the instruction-level rather than basic-block level
- However, there are good reasons for using basic blocks
  - More compact
  - Some optimization passes ("local" optimizations) operate @ basic block level
    - E.g., the implementation of redundant load elimination in `let3.ml`

# Constructing a CFG

- “Forwards“ algorithm:
  - Traverse statements in IR from top to bottom
    - Find *leaders*: first statement & first statement following a label
    - Basic block = leader up to (but not including) next leader
- Alternately, traverse IR from bottom to top, starting a new basic blocks for each terminator and finishing at label (`build_cfg` in `let3.ml`)
  - (Assumes every label has a corresponding terminator. Does not assume every terminator has a corresponding label–implicitly eliminated dead code)
- Can also construct CFG directly from AST

# Generating code from a CFG

- Simple strategy: terminator always compiles to return / jump / conditional jump
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# Generating code from a CFG

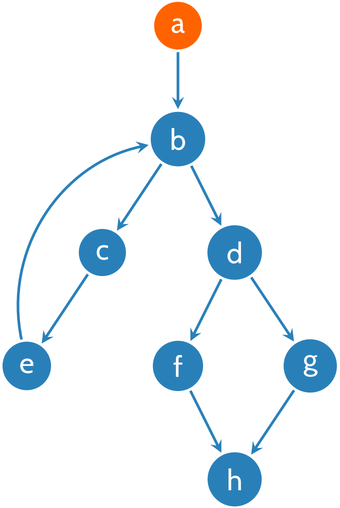
- Simple strategy: terminator always compiles to return / jump / conditional jump
  - "Fall-through" semantics of assembly blocks is never used
- More efficient strategy: elide jumps by ordering blocks appropriately
  - A *covering set of traces* is a set of traces such that
    - Each trace is simple (loop free)
    - Each basic block belongs to a trace

# Generating a covering set of traces

Basic algorithm: depth-first traversal of the CFG

- If at least one successor is *unvisited*, elide jump and place the successor next in sequence
- If all successors are visited, terminate branch

(see `codegen_cfg_trace` in `let3.ml`)



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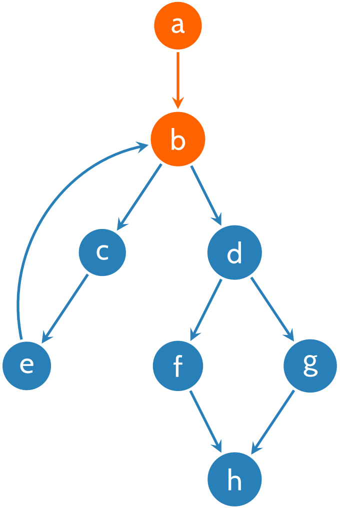

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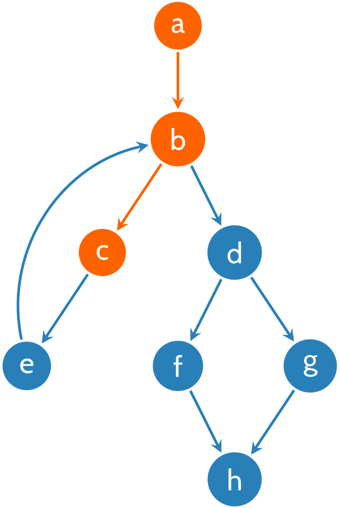

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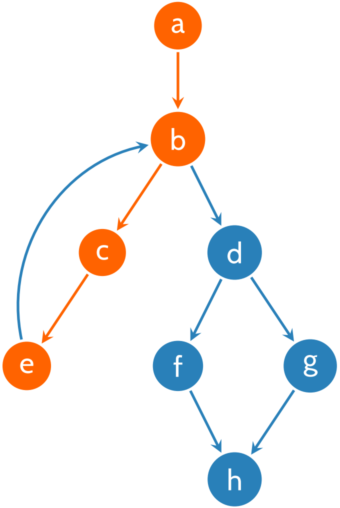

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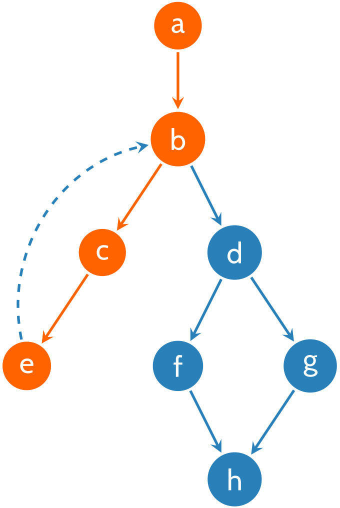

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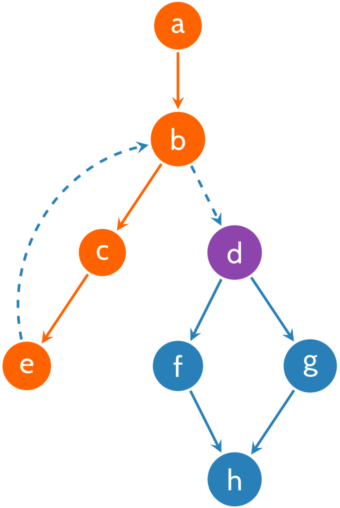

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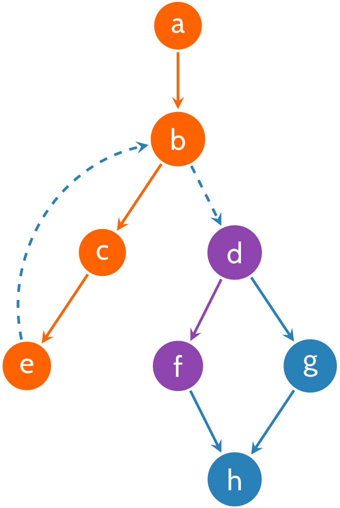

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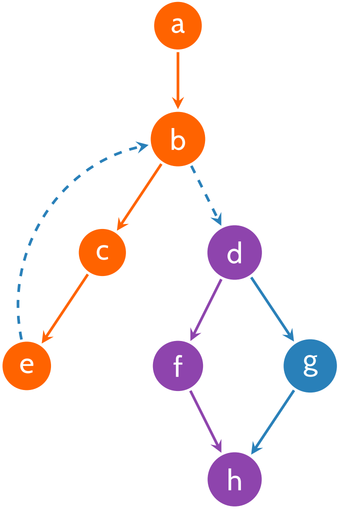

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