Global Value Numbering in Factor

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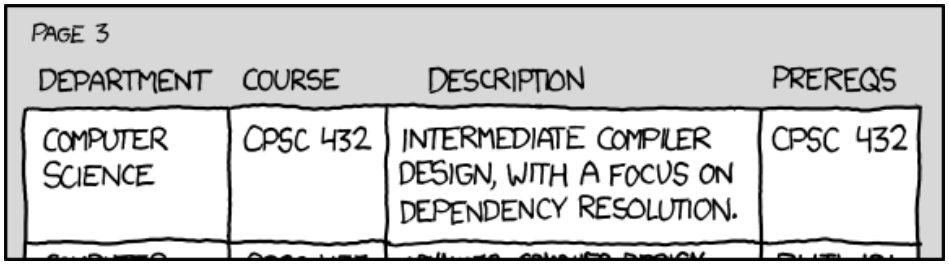


Factor

Factor (`http://factorcode.org/`)

- Started development September 2003—a baby among languages
- Stack-based
- Object-oriented
- Dynamically typed
- Extensive standard library
- High-level, yet fully compiled

Won't really have time to discuss the language in depth

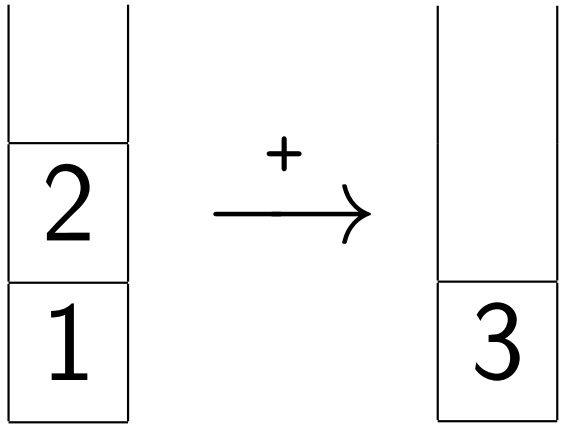
Stacks as an Evaluation Model

Example (Code)

```
1 2 +
```

Example (Execution)

```
push(1);
push(2);
y = pop();    // y = 2;
x = pop();    // x = 1;
push(x + y); // push(3);
```



Organization

Non-optimizing base compiler

- VM written in C++
- Responsible for basic runtime services
  - Garbage collection
  - Method dispatch
  - Polymorphic inline caches
  - ...
- Single pass—outputs assembly stubs for primitives

Optimizing compiler

- Written in Factor code
  - Possible by *bootstrapping*
- Optimizes in passes across two intermediate representations (IRs)
  - High-level IR (`compiler.tree`)
  - Low-level IR (`compiler.cfg`)

High-level IR

- Tree of `node` objects
- Very simple virtual instruction set
  - `#introduce`, `#return`
  - `#push` & `#call`
  - `#renaming`—`#copy` & `#shuffle`
  - `#declare` & `#terminate`
  - `#branch`—`#if` & `#dispatch`
  - `#phi`
  - `#recursive`, `#enter-recursive`, `#call-recursive`, `#return-recursive`
  - `#alien-node`, `#alien-invoke`, `#alien-indirect`, `#alien-assembly`, `#alien-callback`
- Input/output values of stack given unique names

High-level IR

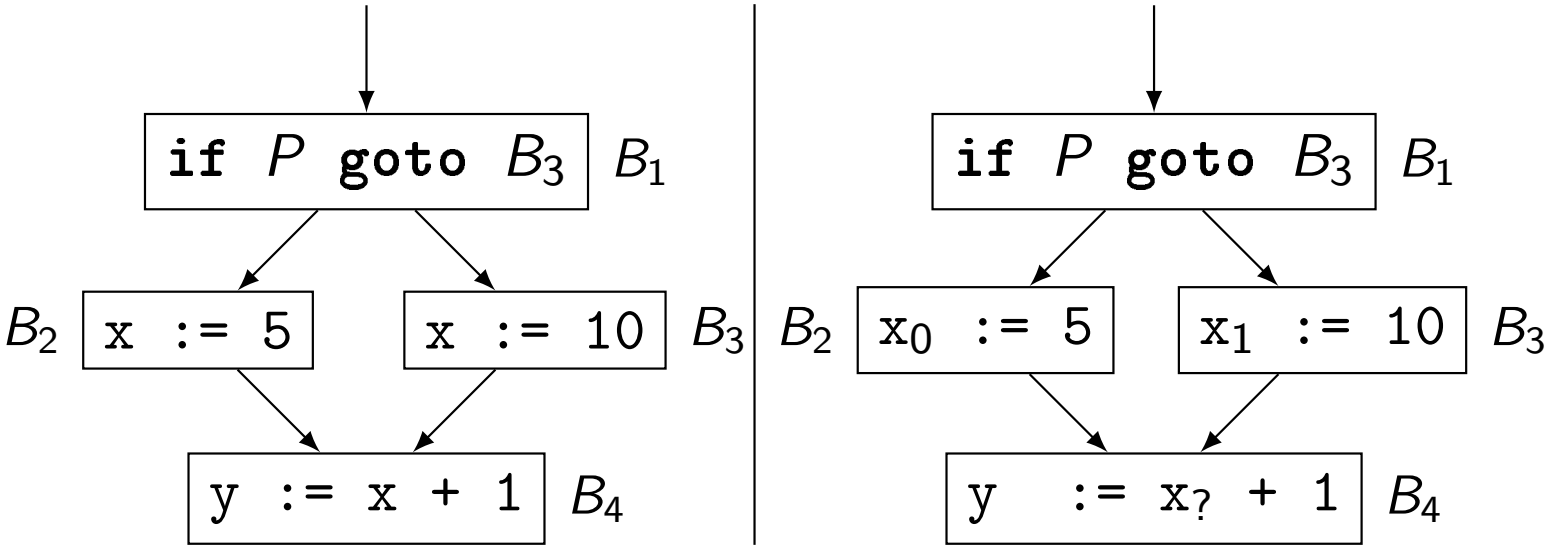
1 2 +

Example

```
V{
    T{ #push { literal 1 } { out-d { 6256273 } } }
    T{ #push { literal 2 } { out-d { 6256274 } } }
    T{ #call
        { word + }
        { in-d V{ 6256274 6256273 } }
        { out-d { 6256275 } }
    }
    T{ #return { in-d V{ 6256275 } } }
}
```

Low-level IR

- Control flow graph (CFG)
  - Basic blocks = maximal sequence of "straight-line" code
  - Directed edges = transfer of control flow
- `insn` objects modeled closely after assembly-like instructions
- Static single assignment (SSA) form



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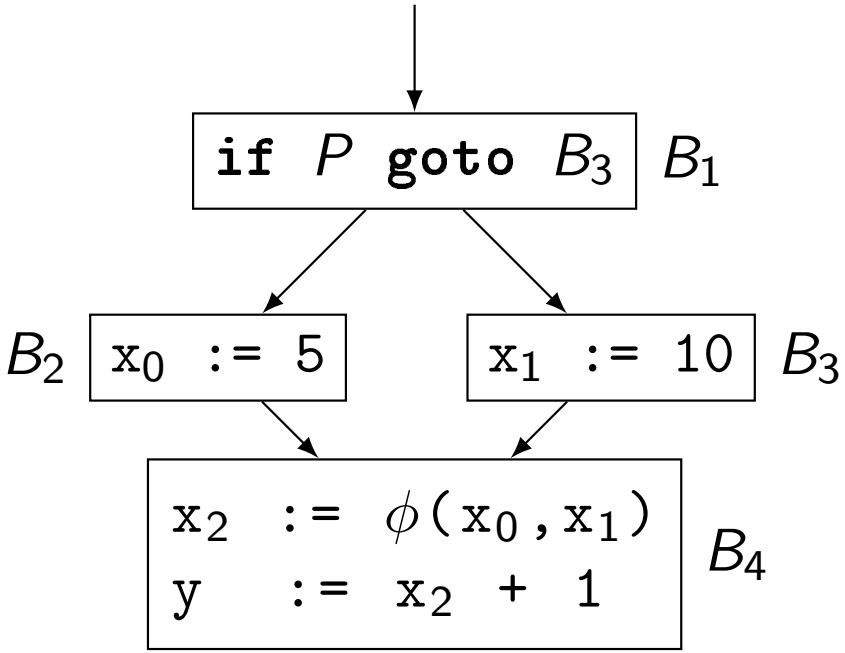

Optimizations—High-level IR

```
: optimize-tree ( nodes -- nodes' )
  [
      analyze-recursive
      normalize
      propagate
      cleanup
      dup run-escape-analysis? [
          escape-analysis
          unbox-tuples
      ] when
      apply-identities
      compute-def-use
      remove-dead-code
      ?check
      compute-def-use
      optimize-modular-arithmetic
      finalize
  ] with-scope ;
```

Optimizations—Low-level IR

```
: optimize-cfg ( cfg -- cfg' )
    optimize-tail-calls
    delete-useless-conditionals
    split-branches
    join-blocks
    normalize-height
    construct-ssa
    alias-analysis
→   value-numbering
    copy-propagation
    eliminate-dead-code ;
```

Value Numbering

Idea: assign each variable a value number

- Equal value numbers $\Longrightarrow$ equal at runtime
- Turn recomputations into ##copy instructions, saving time

General problem is undecidable

- Seek conservative solution
- Discover *Herbrand equivalences*
- Consider two values congruent if
  - They're computed by the same operator
  - Their operands are congruent

Local Value Numbering

- Thought to be invented by Balke in the 1960s
- Largely credited to Cocke & Schwartz in the 1970s
- Current implementation Factor uses

Pro: Easy to understand, implement, and extend

Con: Is local and pessimistic, discovering fewer congruences