Program Analsysis Tools

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- Static Analysis
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Analysis Tools and Compilers

Analysis tools, particularly static, share a great deal with compilers

- Need to parse code & perform limited static analsysi
  - Generally working from ASTs
  - Some exceptions (working from object code or byte code)
- Data flow techniques originated in compiler optimization

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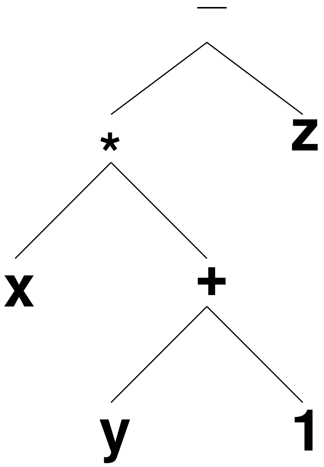
1 ASTs

Abstract Syntax Trees

- Output of a language parser
  - Simpler than parse trees
- Generally viewed as a generalization of operator-applied-to-operands



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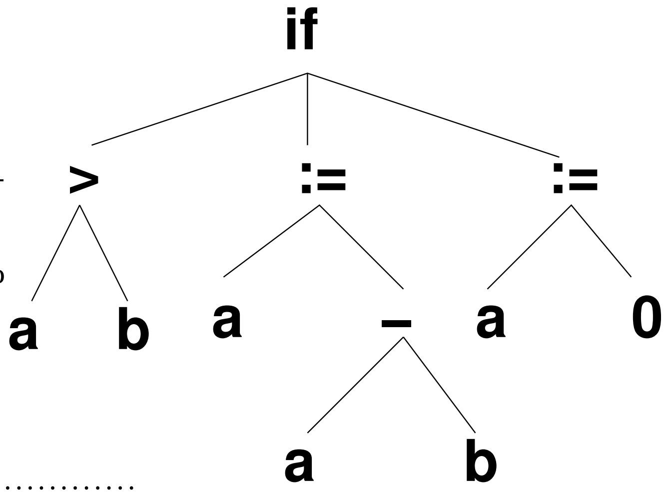
Abstract Syntax Trees (cont.)

- ASTs can be applied to larger constructions than just expressions
- In fact, generally reduce entire program or compilation unit to one AST



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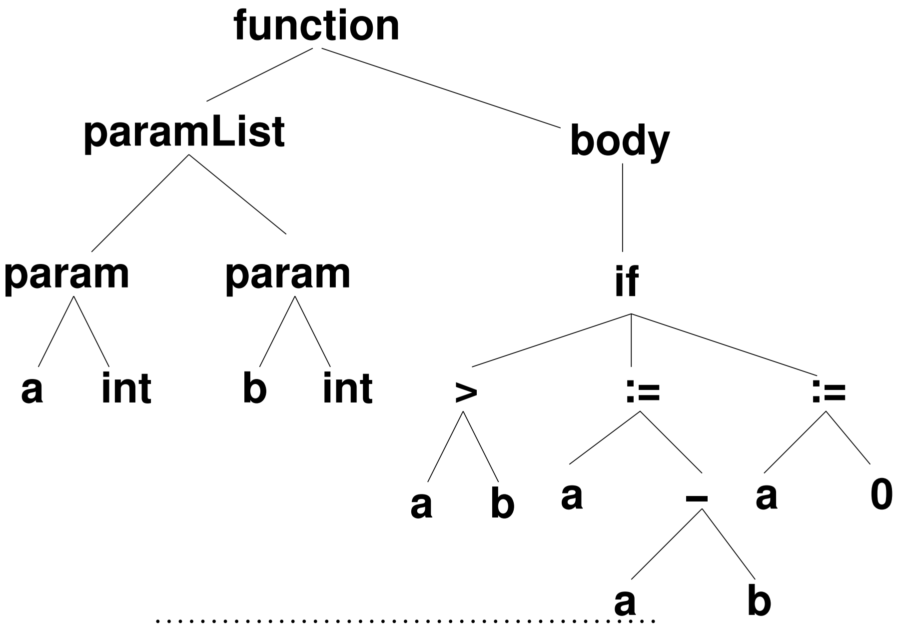
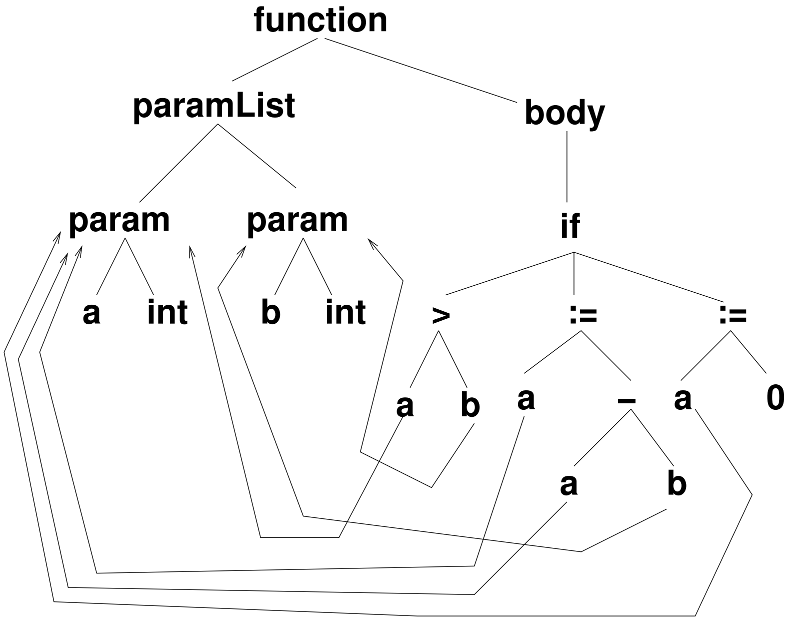
Abstract Syntax Trees (cont.)



Abstract Syntax Graphs



- Semantic analysis pairs uses of variables with declarations
  - Transforming the AST into an ASG

2 Data Flow Analysis

Data Flow Analysis

- All data-flow information is obtained by propagating data flow markers through the program.
- The usual markers are
  - $d(x)$: a definition of variable x (any location where x is assigned a value)
  - $r(x)$: a reference to x (any location where the value of x is used)
  - $u(x)$: an undefinition of x (any location where x becomes undefined/ilegal)

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Propagation of Markers

For each node (basic block) in the control flow graph, we define

- $gen(n)$ = set of data-flow markers generated within node n.
- $kill(n)$ = set of data-flow markers killed within node n.
- $in(n)$ = set of data-flow markers entering node n from elsewhere.

- *out*(n) = set of data-flow markers leaving node n to go elsewhere.

The basic data flow problem is to find *in*() and *out*() for each node given the control flow graph and the *gen*() and *kill*() sets for each node.

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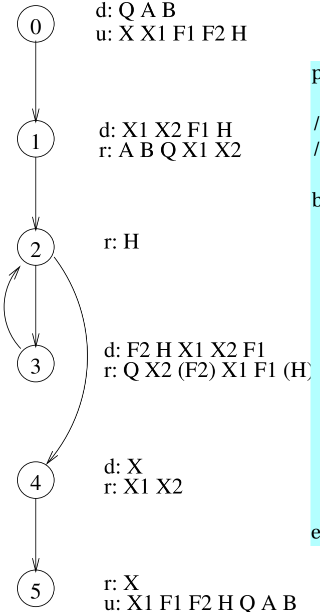
Sample CFG




```
procedure SQRT (Q, A, B: in float;           n0
               X: out float);
// Compute X = square root of Q,
//     given that A <= X <= B
   X1, F1, F2, H: float;
begin
   X1 := A;
   X2 := B;                                   n1
   F1 := Q − X1**2
   H := X2 − X1;
   while (ABS(H) >= 0.001) loop               n2
      F2 := Q − X2**2;
      H := − F2 * ((X2−X1)/(F2−F1));
      X1 := X2;                               n3
      X2 := X2 + H;
      F1 := F2
   end loop;
   X := (X1 + X2) / 2.;                       n4
end SQRT;                                     n5
```

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Reaching Definitions

A definition $d_i(x)$ *reaches* a node n_j iff there exists a path from n_i to n_j on which x is neither defined nor undefined.

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The Reaching DF Problem

$gen(n)$ = set of definitions occurring in n and reaching the end of n.

$kill(n)$ = set of all definitions $d_i(x)$ in the CFG such that x is defined or undefined within n.

$$in(n) = \bigcup_{m \epsilon pred(n)} out(m)$$

$$out(n) = (in(n) - kill(n)) \cup gen(n)$$

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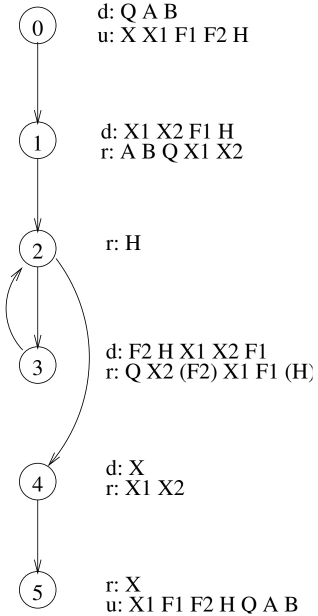
Sample Nodes



$$
\begin{aligned}
gen(n_0) &= \{d_0(Q), d_0(A), d_0(B)\} \\
gen(n_1) &= \{d_1(X1), d_1(X2), d_1(F1), d_1(H)\} \\
gen(n_2) &= \{\} \\
gen(n_3) &= \{d_3(F2), d_3(H), d_3(X1), d_3(X2), \\
&\quad d_3(F1)\} \\
gen(n_4) &= \{d_4(X)\} \\
gen(n_5) &= \{\}
\end{aligned}
$$

. . . .

Sample Nodes (kill)

$$
\begin{aligned}
kill(n_0) &= \{d_0(Q), d_0(A), d_0(B), d_1(X1), d_1(X2), \\
&\quad d_1(F1), d_1(H), d_3(F2), d_3(H), d_3(X1), \\
&\quad d_3(X2), d_3(F1), d_4(X)\} \\
kill(n_1) &= \{d_1(X1), d_1(X2), d_1(F1), d_1(H), d_3(H), \\
&\quad d_3(X1),\} \\
kill(n_2) &= \{\} \\
kill(n_3) &= \{d_1(X1), d_1(X2), d_1(F1), d_1(H), d_3(F2), \\
&\quad d_3(H), d_3(X1), d_3(X2), d_3(F1)\} \\
kill(n_4) &= \{d_4(X)\} \\
kill(n_5) &= \{d_0(Q), d_0(A), d_0(B), d_1(X1), d_1(X2), \\
&\quad d_1(F1), d_1(H), d_3(F2), d_3(H), d_3(X1), \\
&\quad d_3(X2), d_3(F1)\}
\end{aligned}
$$

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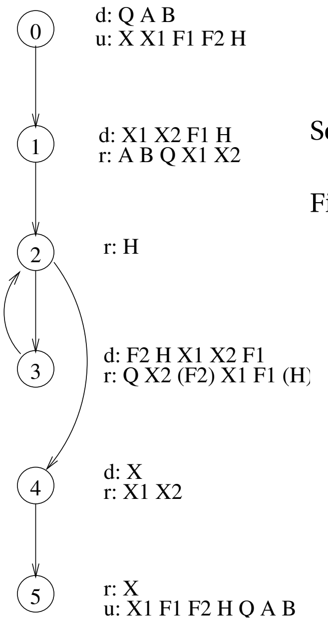
Solving for Reaching Defs



Solving iteratively, we start with $in(n) = out(n) = \{\}$, and propagate definitions.

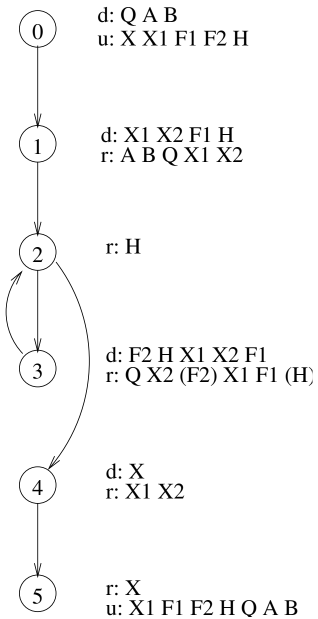
First Iteration:

$$in(0) = \{\}$$
$$out(0) = gen(0)$$

$$in(1) = gen(0)$$
$$out(1) = gen(0) \cup gen(1)$$

....

Iteration 1 (cont.)



$$
\begin{aligned}
in(2) &= gen(0) \cup gen(1) \\
out(2) &= gen(0) \cup gen(1)
\end{aligned}
$$

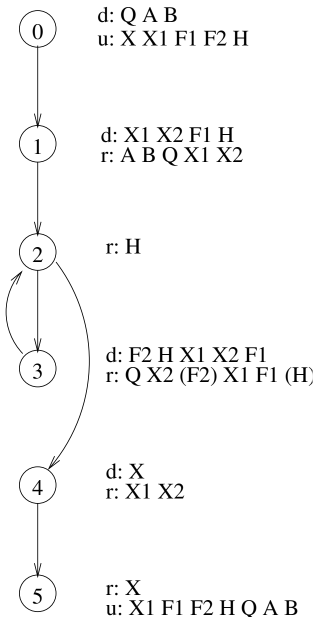
$$
\begin{aligned}
in(3) &= gen(0) \cup gen(1) \\
out(3) &= \{d_0(Q), d_0(A), d_0(B), d_3(F2), d_3(H), \\
&\quad d_3(X1), d_3(X2), d_3(F1)\}
\end{aligned}
$$

$$
\begin{aligned}
in(4) &= gen(0) \cup gen(1) \\
out(4) &= gen(0) \cup gen(1) \cup \{d_4(X)\}
\end{aligned}
$$

$$
\begin{aligned}
in(5) &= gen(0) \cup gen(1) \cup \{d_4(X)\} \\
out(5) &= \{d_4(X)\}
\end{aligned}
$$

....

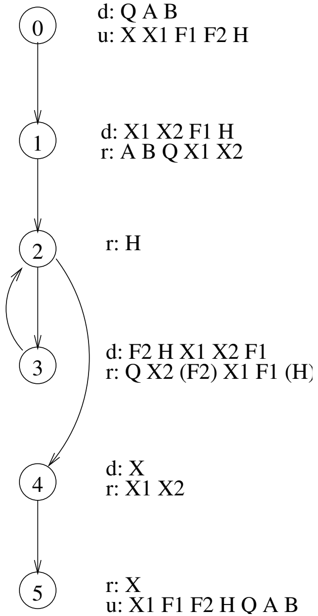
Iteration 2



$$
\begin{aligned}
in(0) &= \text{unchanged} \\
out(0) &= \text{unchanged} \\
in(1) &= \text{unchanged} \\
out(1) &= \text{unchanged} \\
in(2) &= gen(0) \cup gen(1) \cup \{d_3(F2), \\
&\quad d_3(H), d_3(X1), d_3(X2), d_3(F1)\} \\
out(2) &= gen(0) \cup gen(1) \cup \{d_3(F2), d_3(H), \\
&\quad d_3(X1), d_3(X2), d_3(F1)\}
\end{aligned}
$$

....

Iteration 2 (cont.)



$$
\begin{aligned}
in(3) &= gen(0) \cup gen(1) \cup \{d_3(F2), d_3(H),\\
&\quad d_3(X1), d_3(X2), d_3(F1),\}\\
out(3) &= \text{unchanged}
\end{aligned}
$$

$$
\begin{aligned}
in(4) &= gen(0) \cup gen1 \cup \{d_3(F2), d_3(H),\\
&\quad d_3(X1), d_3(X2), d_3(F1),\}\\
out(4) &= gen(0) \cup gen1 \cup \{d_3(F2), d_3(H),\\
&\quad d_3(X1), d_3(X2), d_3(F1), d_4(X)\}
\end{aligned}
$$

$$
\begin{aligned}
in(5) &= gen(0) \cup gen1 \cup \{d_3(F2), d_3(H),\\
&\quad d_3(X1), d_3(X2), d_3(F1), d_4(X)\}\\
out(5) &= \text{unchanged}
\end{aligned}
$$

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Data Flow Anomalies

The reaching definitions problem can be used to detect anomolous patterns that *may* reflect errors.

- *ur anomalies*: if an undefinition of a variable *reaches* a reference of the same variable
- *dd anomalies*: if a definition of a variable *reaches* a definition of the same variable
- *du anomalies*: if a definition of a variable *reaches* an undefinition of the same variable

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Available Expressions

An expression e is *available* at a node n iff every path from the start of the program to n evaluates e, and iff, after the last evaluation of e on each such path, there are no subsequent definitions or undefinitions to the variables in e.

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The Available DF Problem

$gen(n)$ = set of expressions evaluated in n containing no variables subsequently defined or undefined within n.

$kill(n)$ = set of all expressions in the program containing variables that are defined or undefined within n.

$$in(n) = \bigcap_{m \epsilon pred(n)} out(m)$$

$$out(n) = (in(n) - kill(n)) \cup gen(n)$$

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Live Variables

A variable x is *live* at node n iff there exists a path starting at n along which x is used without prior redefinition.

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The Live Variable DF Problem

$gen(n)$ = set of variables used in n without prior definition.

$kill(n)$ = set of variables defined within n.

$$in(n) = gen(n) \cup (out(n) - kill(n))$$

$$out(n) = \bigcup_{m \epsilon succ(n)} in(m)$$

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Data Flow and Optimization

Optimization Technique	Data-Flow Information
Constant Propagation	reach
Copy Propagation	reach
Elimination of Common Subexpressions	available
Dead Code Elimination	live, reach
Register Allocation	live
Anomaly Detection	reach
Code Motion	reach

3 Static Analysis Tools

3.1 Style and Anomaly Checking

Lint

Perhaps the first such tool to be widely used, **lint** (1979) became a staple tool for C programmers. Combines static analysis with style recommendations, e.g.,

- data flow anomalies
- potential arithmetic overflow
  - e.g., storing an *int* calculation in a *char*

- conditional statements with constant values
- potential = versus == confusion

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Is there room for lint-like tools?

- **lint** was a response, in part, to the weak capabilities of early C compilers
- Much of what **lint** does is now handled by optimizing compilers
  - However compilers seldom do cross-module or even cross-function analysis

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FindBugs

- Open source project from U.Md.
- Works on compiled Java bytecode
- Sample report

- Can be run via
  - GUI
  - ant
  - Eclipse
  - maven

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What Bugs does FindBugs Find?

- “Bugs” categorized as
  - Correctness bug: an apparent coding mistake
  - Bad Practice: violations of recommended coding practices.
  - Dodgy: code that is “confusing, anomalous, or written in a way that leads itself to errors”
- Bugs are also given “priorities” (p1, p2, p3 from high to low)
- Bug list

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PMD

- PMD, source analysis for Java, JavaScript, XSL
  - CPD, “copy-paste-detector” for many programming languages
- Works on source code
- Sample reports (PMD & CPD)
- Can be run via bii ant
  - maven
  - eclipse

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PMD Reports

- Configured by selecting “rule set” modules
  - Otherwise, appears to lack categories & priorities
- Cross reference to source location

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3.2 Reverse Compilers & Obfuscators

Reverse Compilers

a.k.a. “uncompilers”

- Generate source code from object code
- Originally clunky & more of a curiosity than usable tools
  - Improvements based on
    - “deep” knowledge of compilers (aided by increasingly limited field of available compilers)
    - Information-rich object codes (e.g., Java bytecode formats)
- Legitimate uses include
  - reverse-engineering
  - generating input for source-based analysis tools
- But also great tools for plagiarism

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Java and Decompilation

- Java is a particularly friendly field for decompilers
  - Rich object code format
  - Nearly monopolistic compiler suite
- Options for "protecting" programs compiled in Java:
  - **gjc**: compile into native code with a far less popular compiler
  - obfuscators

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Java Obfuscators

Work by a combination of

- Renaming variables, functions, and classes to meaningless, innocuous, and very similar name sets
  - Challenge is to preserve those names of entry points needed to execute a program or applet or make calls upon a library's public API
  - Stripping away debugging information (e.g., source code file names and line numbers associated with blocks of code)

  - Applying optimization techniques to reduce code size while also confusing the object-to-source mapping

Example, ygaurd

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4 Dynamic Analysis Tools

Dynamic Analysis Tools

Not all useful analysis can be done statically

- Profiling
- Memory leaks, corruption, etc.
- Data structure abuse

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Abusing Data Structures

- Traditionally, the C++ standard library does not check for common abuses such as over-filling and array or accessing non-existent elements

  - Various authors have filled in with "checking" implementations of the library for use during testing and debugging

- In a sense, the **assert** command of C++ and Java is the language's own extension mechanism for such checks.

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4.1 Pointer/Memory Errors

Memory Abuse

- Pointer errors in C++ are both common and frustrating
  - Traditionally unchecked by standard run-time systems
- Monitors can be added to help catch these
  - In C++, link in a replacement for `malloc` & `free`

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How to Catch Pointer Errors

- Use *fenceposts* around allocated blocks of memory

- check for unchanged fenceposts to detect over-writes
- Check for fenceposts before a delete to detect attempts to delete addresses other than the start of an allocated block

- Add tracking info to allocated blocks indicating location of the allocation call
  - Scan heap at end of program for unrecovered blocks of memory
  - Report on locations from which those were allocated
- Add a “freed” bit to allocated blocks that is cleared when first allocated and set when the block is freed
  - Detect when a block is freed twice

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Memory Analysis Tools

- Purify is a well-known commercial (pricey) tool
- At the other end of the spectrum, LeakTracer is a small, simple, but capable open source package that I’ve used for many years
  - Works with gcc/g++/gdb compiler suite

```
~/p/arc# ea/LeakTracer/leak-analyze ./arc
Gathered 8 (8 unique) points of data.
(gdb)
Allocations: 1 / Size: 36
0x80608e6 is in NullArcableInstance::NullArcableInstance(void) (Machine.cc:40).
39      public:
40          NullArcableInstance() : ArcableInstance(new NullArcable) {}

Allocations: 1 / Size: 8
0x8055b02 is in init_types(void) (Type.cc:119).
118 void init_types() {
119 Type::Integer = new IntegerType;

Allocations: 1 / Size: 132 (new[])
0x805f4ab is in Hashtable<NativeCallable, String, false, true>::Hashtable(unsigned int) (ea/h/Has
14 Hashtable (uint _size = 32) : size(_size), count(0) {
15 table = new List<E, own> [size];
```

....

4.2 Profilers

Profilers

Profilers provide info on where a program is speding most of its execution time

- May express measurements in
  - Elapsed time
  - Number of executions
- Granularity may be at level of
  - functions
  - individual lines of code
- Measurement may be via
  - Probes inserted into code
  - Statistical sampling of CPU program counter register

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Profiling Tools

- **gprof** for C/C++, part of the GNU compiler suite
  - Refer back to earlier lesson on statement and branch coverage
  - **gprof** is, essentially, the generalization of **gcov**
- **jvisualm** for Java, part of the Java SDK
- Provides multiple monitoring tools, including both CPU and memory profiling

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