CMSC 430

Introduction to Compilers

Fall 2018

Data Flow Analysis
Applications and Implementations

Data Flow Analysis

- A framework for proving facts about programs
- Reasons about lots of little facts
- Little or no interaction between facts
  - Works best on properties about *how* program computes
- Based on all paths through program
  - Including infeasible paths
- Operates on control-flow graphs, typically

Space of Data Flow Analyses

	May	Must
Forward	Reaching definitions	Available expressions
Backward	Live variables	Very busy expressions

- Most data flow analyses can be classified this way
  - A few don't fit: bidirectional analysis
- Lots of literature on data flow analysis

Applications: Reaching Defs.

- **Constant propagation**: if all definitions of a given variable's use are the same constant value, just assign the constant directly.

- **Loop invariant code motion**: if an expression is computed in a loop, but all of the components are defined outside the loop, the code can move.

Applications: Liveness

- **Register allocation**: variables that are not live in a given basic block (or subgraph) do not need to be in registers. More on this later.
- **Dead code elimination**: variables that are assigned but not live after the assignment don’t need to be computed at all.

Applications: Available Exprs.

- **Common sub-expression elimination:** create a new variable containing the result of an expression. Replace subsequent uses of the expression with a read from the variable.

Applications: Very Busy Exprs.

- **Code motion**, e.g., move the computation of an expression to before a loop or branch.

- If the same expression will be computed on every branch of a conditional, or every time through the loop, it can be pre-computed.

```
if (a < b) {
   x = a - b
} else {
   y = a - b
}
```

```
t = a - b
if (a < b) {
   x = t
} else {
   y = t
}
```

Implementations

- Optimizing compilers implement data-flow analysis

- GCC:
  - https://www.airs.com/dnovillo/200711-GCC-Internals/200711-GCC-Internals-4-cfg-cg-df.pdf
  - https://github.com/gcc-mirror/gcc/blob/master/gcc/df-core.c
  - https://github.com/gcc-mirror/gcc/blob/master/gcc/df-problems.c

- Clang:
  - https://clang.llvm.org/doxygen/LiveVariables_8cpp_source.html
  - https://github.com/llvm-mirror/clang/blob/master/lib/Analysis/LiveVariables.cpp
  - https://github.com/llvm-mirror/clang/blob/master/lib/Analysis/UninitializedValues.cpp

Implementations (cont.)

- Static analysis and bug-finding tools also use DFA

- Haskell package for LLVM:
  http://hackage.haskell.org/package/llvm-analysis-0.3.0/docs/LLVM-Analysis-Dataflow.html

- C Intermediate Language (CIL)
  - https://github.com/cil-project/cil
    http://cil-project.github.io/cil/doc/html/cil/
  - Written in OCaml!
  - Stable but no longer directly maintained
  - Used in Frama-C: http://frama-c.com/

Using CIL on Grace

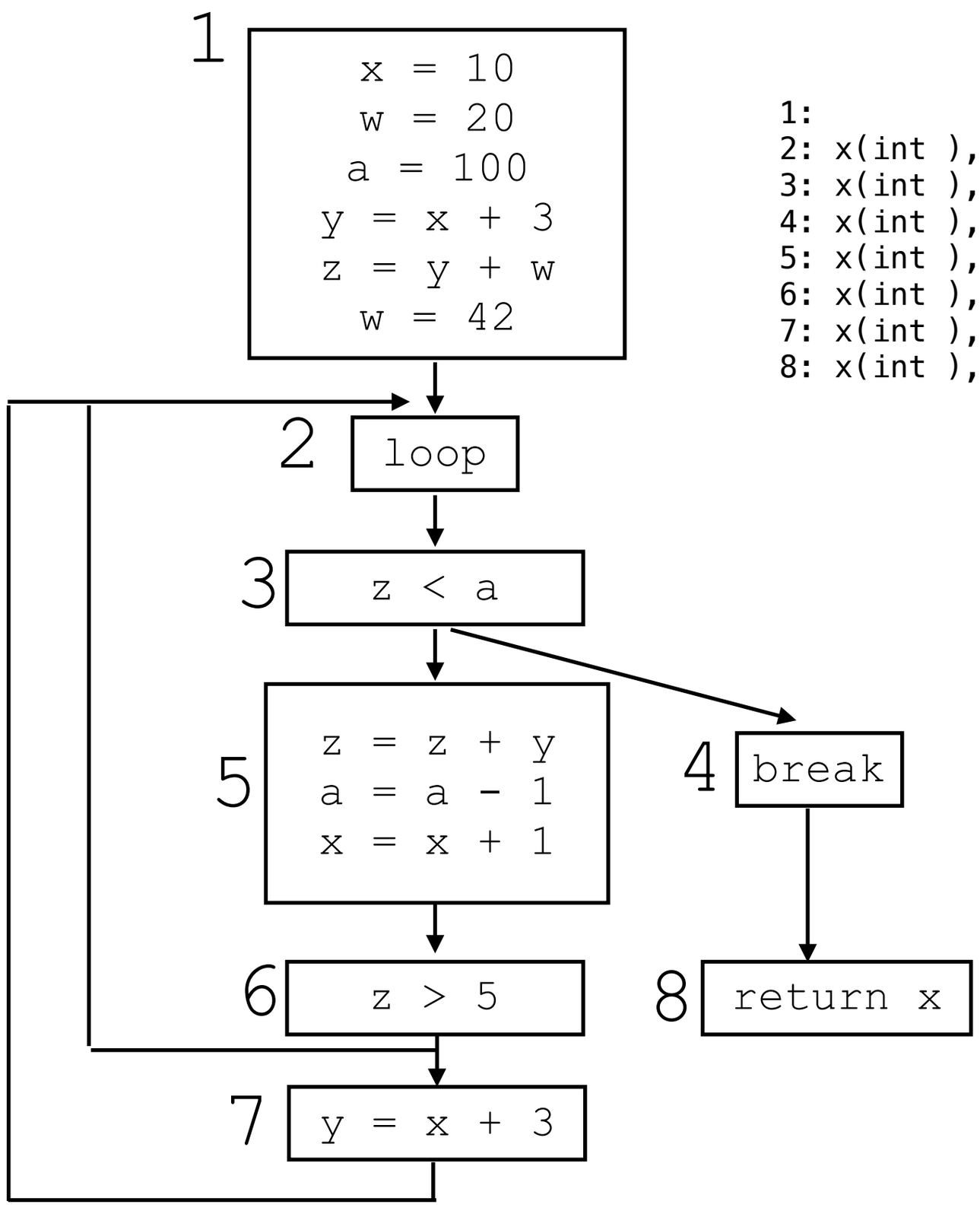
```
$ ssh grace.umd.edu
$ source /afs/glue.umd.edu/class/fall2018/cmsc/430/0201/public/.opam/opam-init/init.csh
$ git clone https://github.com/cil-project/cil
$ cd cil
$ ./configure && make
$ ./bin/cilly -help | less
```

```
$ ./bin/cilly \
   --save-temps \
   --doLiveness \
   --live_func=main \
   --live_debug \
   /afs/glue.umd.edu/class/fall2018/cmsc/430/0201/public/src/ex1/ex1.c
```

ex1.c

```
int main(int argc, char *argv[]) {
    int x, y, z, w, a;

    x = 10;
    w = 20;
    a = 100;

    y = x + 3;
    z = y + w;
    w = 42;

    while (z < a) {
        z = z + y;
        a = a - 1;
        x = x + 1;
        if (z > 5) {
            y = x + 3;
        }
    }

    return x;
}
```

main() CFG




```
1:
2: x(int ),y(int ),z(int ),a(int ),
3: x(int ),y(int ),z(int ),a(int ),
4: x(int ),
5: x(int ),y(int ),z(int ),a(int ),
6: x(int ),y(int ),z(int ),a(int ),
7: x(int ),z(int ),a(int ),
8: x(int ),
```