Advanced

T pics

in

C mpilers

DFA

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Outline

- DFA (summary from 323)

- Data Flow Engine in NOELLE

- Data Flow Analyses available in NOELLE

The need for DFAs

- We constantly need to improve programs
  (e.g., speed, energy efficiency, memory requirements)
- We constantly need to identify opportunities
- After having found an opportunity (e.g., propagating constants),
  you need to ask yourself:
  - What do I need to know to take advantage of this opportunity?
    (e.g., I need to know the possible values a given variable might have
    at a given point in the program)
  - How can I automatically compute this information?
    Often the solution relies on understanding
    how data flows through the code.
    This is often done by designing ad-hoc DFAs

New transformations and analyses

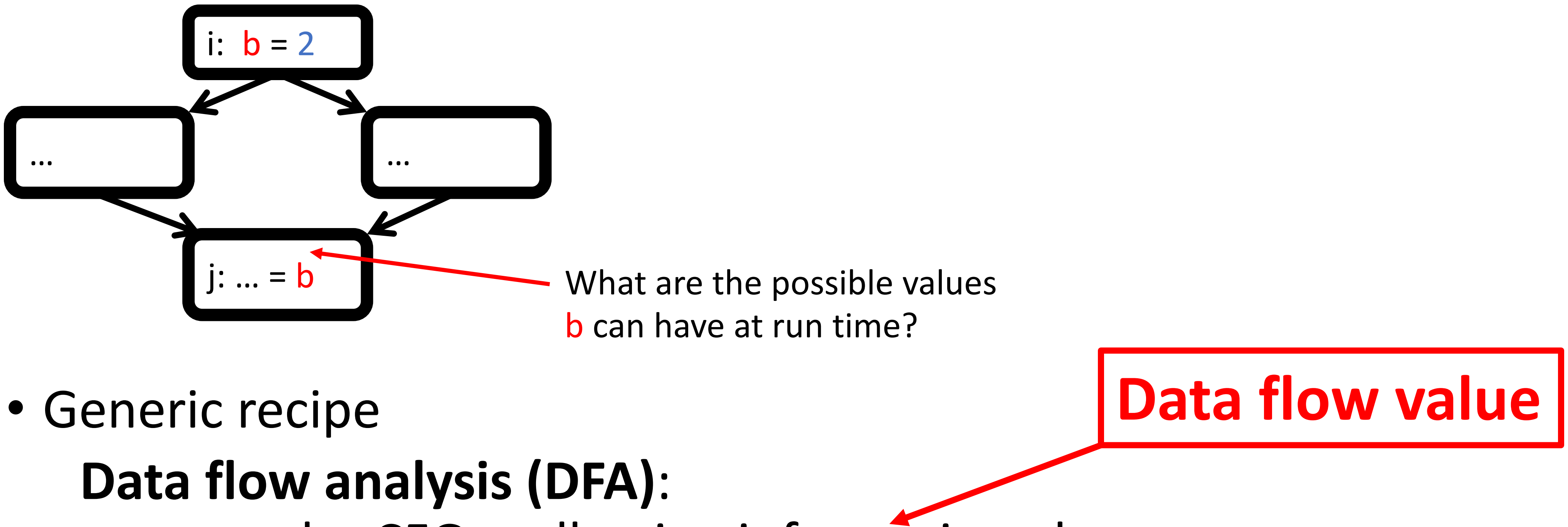
- New transformations (often) need to understand specific and new code properties related to how data might change through the code
  - So we need to know how to design a new data flow analysis that identifies these new code properties
- Generic recipe

  Data flow analysis (DFA):
  traverse the CFGs collecting information about what may happen at run time (Conservative approximation)

  Data flow value

  Transformation:
  Modify the code based on the result of data flow analysis
  (Correctness guaranteed by the conservative approximation of DFA)

New transformations and analyses



- Generic recipe

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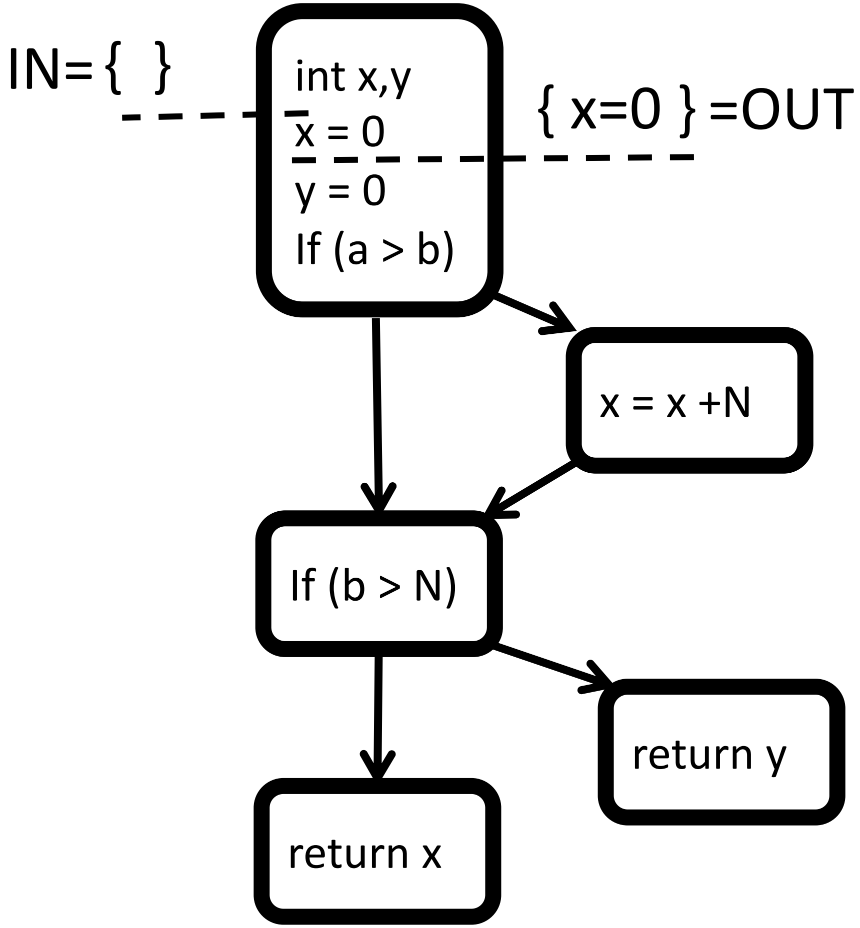
Data-flow expressed in CFG



Data-flow value:
set of all possible program states
that can be observed
at a given program point

e.g., all definitions in the program
that might have been executed
before that point

Data-flow analysis
computes IN and OUT sets
by computing
the DFA-specific transfer functions

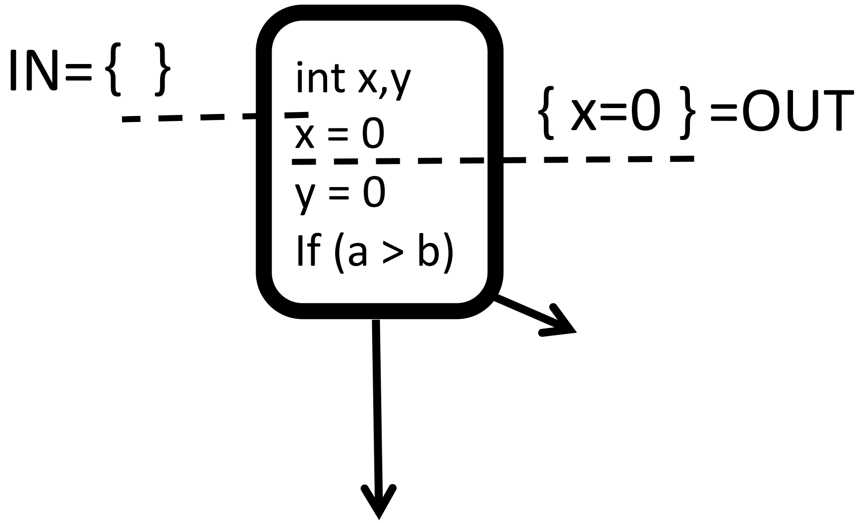
Transfer functions

- Let *i* be an instruction: IN[*i*] and OUT[*i*] are the set of data-flow values before and after the instruction *i* of a program
- A transfer function *fs* relates the data-flow values before and after an instruction *i*
- In a forward data-flow problem

$$OUT[\ i\ ] = fs(\ IN[\ i\ ]\ )$$

- In a backward data-flow problem

$$IN[\ i\ ] = fs(\ OUT[\ i\ ]\ )$$



***fs* is DFA-specific**

Transfer function internals: Y[*i*] = *fs* (X[*i*])

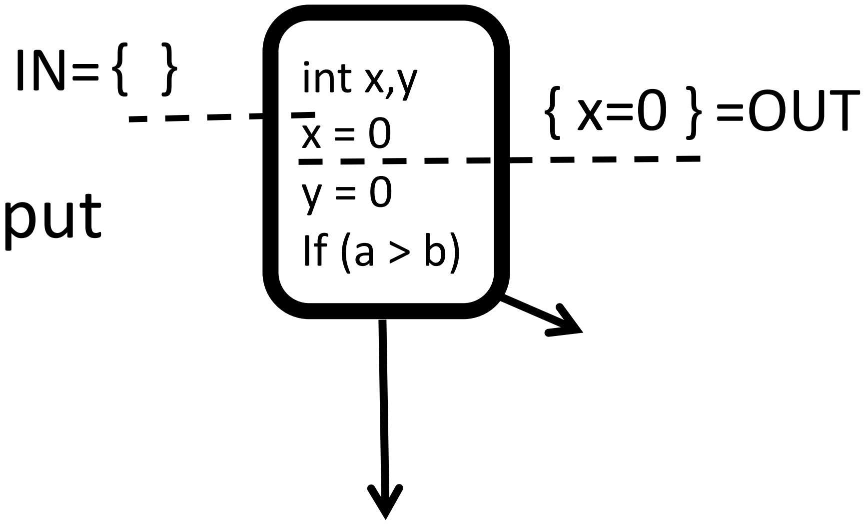
- It relies on information that reaches i

- It transforms such information to propagate the result to the rest of the CFG

GEN[i] = data flow value added by i

KILL[i] = data flow value removed because of i

- To do so, it relies on information specific to i
  - Encoded in GEN[i], KILL[i]
  - *fs* uses GEN[i] and KILL[i] to compute its output



- GEN[i] and KILL[i] are DFA-specific and (typically) data/control flow independent!

DFA steps

1) Define the DFA-specific sets GEN[i] and KILL[i], for all i

2) Implement the DFA-specific transfer function *fs*

3) Compute all IN[i] and OUT[i] following a DFA-generic algorithm

   OUT[i] = *fs* (IN[i])

   IN[i] = *fs* (OUT[i])

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The need for a data flow engine

- Implementing a data flow analysis
  that scales well with the number of instructions takes time and efforts
- The typical required optimizations (see 323) are DFA-agnostic
- A data-flow engine, therefore, can be built once
  and used by many data-flow analyses
- LLVM does not provide a data-flow engine
- NOELLE provides a data-flow engine
  to accelerate the development of data-flow analyses
  accelerating therefore research

Let’s build our first DFA with NOELLE

Normalize the code

Code must be normalized before you use NOELLE

- noelle-norm MYIR.bc –o IR.bc
  or
- noelle-simplification MYIR.bc –o IR.bc

Fetching the data flow engine

```
/*
 * Fetch NOELLE
 */
auto& noelle = getAnalysis<Noelle>();
```

```
/*
 * Fetch the data flow engine.
 */
auto dfe = noelle.getDataFlowEngine();
```

arcana::noelle::DataFlowEngine *

Using the data-flow engine

```
/*
 * Fetch the entry point.
 */
auto fm = noelle.getFunctionsManager();
auto mainF = fm->getEntryFunction();
```

It includes
the final IN and OUT for all instructions

```
auto customDfr = dfe.applyBackward(
  mainF,
  computeGEN,
  computeKILL,
  computeIN,
  computeOUT
  );
```

void (Instruction *, DataFlowResult *)

void (
    std::set<Value *>& IN,
    Instruction *inst,
    DataFlowResult *df
)

New DFA example

Goal: identify the load instructions that may execute after a given load instruction

for all load instructions

Correct (and conservative) solution:

- Backward DFA
- GEN[i] = {i} if i is a load instruction, {} otherwise
- KILL[i] = {}
- OUT[i] = $\bigcup_{s = successors(i)}$ IN[s]
- IN[i] = GEN[i] ∪ OUT[i]

New DFA example

- GEN[i] = {i} if i is a load instruction, {} otherwise

```
auto computeGEN = [](Instruction *i, DataFlowResult *df) {
  if (!isa<LoadInst>(i)){
    return ;
  }
  auto& gen = df->GEN(i);
  gen.insert(i);
  return ;
};
```

New DFA example

- KILL[i] = {}

```
auto computeKILL = [](Instruction *, DataFlowResult *) {
  return ;
};
```

New DFA example

- $OUT[i] = \bigcup_{s = successors(i)} IN[s]$

```
auto computeOUT = [](Instruction *inst,
                     Instruction *successor,
                     std::set<Value *> &OUT,
                     DataFlowResult *df) {
  auto &inS = df->IN(successor);
  OUT.insert(inS.begin(), inS.end());
  return;
};
```

New DFA example

- IN[i] = GEN[i] ∪ OUT[i]

```
auto computeIN =
    [](Instruction *inst, std::set<Value *> &IN, DataFlowResult *df) {
      auto &genI = df->GEN(inst);
      auto &outI = df->OUT(inst);
      IN.insert(outI.begin(), outI.end());
      IN.insert(genI.begin(), genI.end());
      return;
    };
```

Computing DFA result

```
auto customDfr = dfe.applyBackward(
  mainF,
  computeGEN,
  computeKILL,
  computeIN,
  computeOUT
  );
```

Using DFA result

```
for (auto inst : instructions(mainF)){
  if (!isa<LoadInst>(inst)){
    continue ;
  }
  auto insts = customDfr->OUT(inst);
  errs() << " Next are the " << insts.size() << " instructions ";
  errs() << "that could read the value loaded by " << *inst << "\n";
  for (auto possibleInst : insts){
    errs() << "    " << *possibleInst << "\n";
  }
}
```

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Running available data flow analyses

```
/*
 * Fetch NOELLE
 */
auto& noelle = getAnalysis<Noelle>();
```

```
auto dfa = noelle.getDataFlowAnalyses();
```

```
/*
 * Fetch the entry point.
 */
auto fm = noelle.getFunctionsManager();
auto mainF = fm->getEntryFunction();
```

```
auto dfr = dfa.runReachableAnalysis(mainF);
```

Always have faith in your ability

Success will come your way eventually

Best of luck!