GRAPHITE: Towards a Declarative Polyhedral Representation

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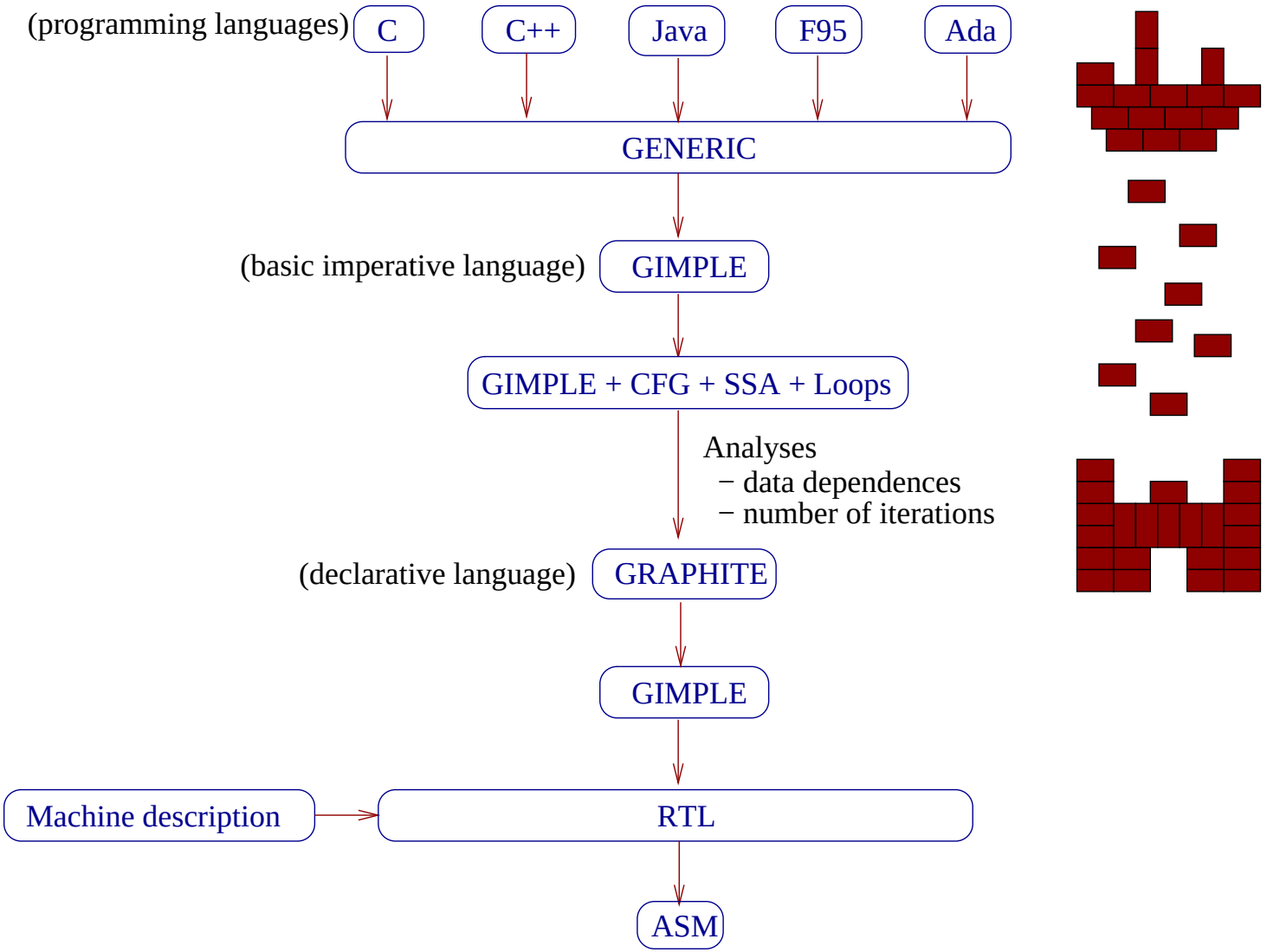
Architecture of GCC and Loop Nest Optimizer



GRAPHITE: Gimple Represented as Polyhedra

- polyhedral representation based on matrices
- static control parts (SCoPs)
- parameters
- iteration domains
- memory access functions
- data dependence relations
- statement scheduling

Reaching Definitions (Imp)

From a given point (static sequence + iteration),
RD is the last point where a variable was written.

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- for scalar variables:
  - RD is statically computable
  - SSA statically translates RDs to declarations
- for arrays:
  - RD statically uncomputable (undecidable address expressions)
  - RD approximations: array regions $\subset$ data dependence relations
  - exact static RD: insert disambiguation copies = privatization

Data Dependence Relations (Imp)

For two memory operations in static sequence

```
A; ...; B
```

executed at iteration points k_A and k_B, and accessing memory locations $f_A(k_A)$ and $f_B(k_B)$, the dependence relation between A and B is the set of iterations (k_A, k_B) satisfying

$$\begin{cases} k_A \in iterDomain(A) \\ k_B \in iterDomain(B) \\ f_A(k_A) = f_B(k_B) \end{cases}$$

Data Dependence Relations (Imp)

- DDRs (k_A, k_B) track only iterations in RDs
- need to keep on the side the sequence

  `A; ...; B`
- redundant with the SSA for scalar variables

Polyhedral Representation (PR) with SSA?

- aggregate GIMPLE operations
- reconstruct higher level FORTRAN array ops
- keep the PR in SSA form

Purely Declarative Polyhedral Representation?

- no statements in the PR
- no schedule in the PR
- generate schedules and statements in out-of-PR

Questions?

Problems with Classical LNO Transforms

Motivations for GRAPHITE:

- difficult to undo loop transforms
- order of transforms fixed once for all
- difficult to compose
- invalidated data deps: ad-hoc correction or rebuild
- transform applied to loop bodies

Limitations of GRAPHITE

SCoP(Static Control Parts) and their limits

- working on dominator trees
- loops containing a harmful basic block are split
- basic blocks with side effect statements are split

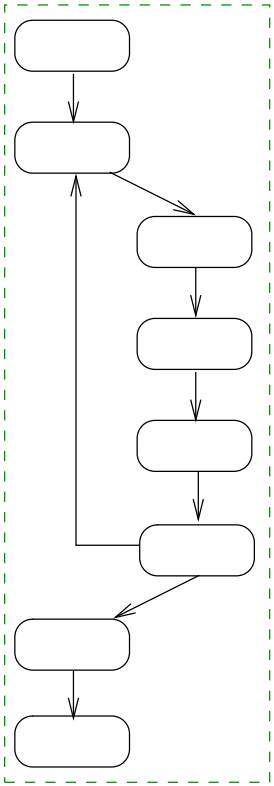
Harmful statements:

- function calls
- side effects (volatile, asm, etc.)
- non supported inductions (exp, wrap, etc.)

Selecting interesting SCoPs

Example: building SCoPs

- SCoPs built on top of the CFG:



basic blocks of the SCoP

- contain only affine constructs, no side effects

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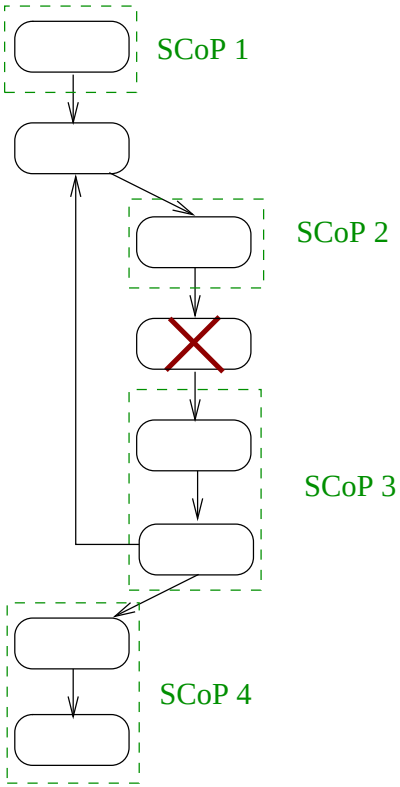
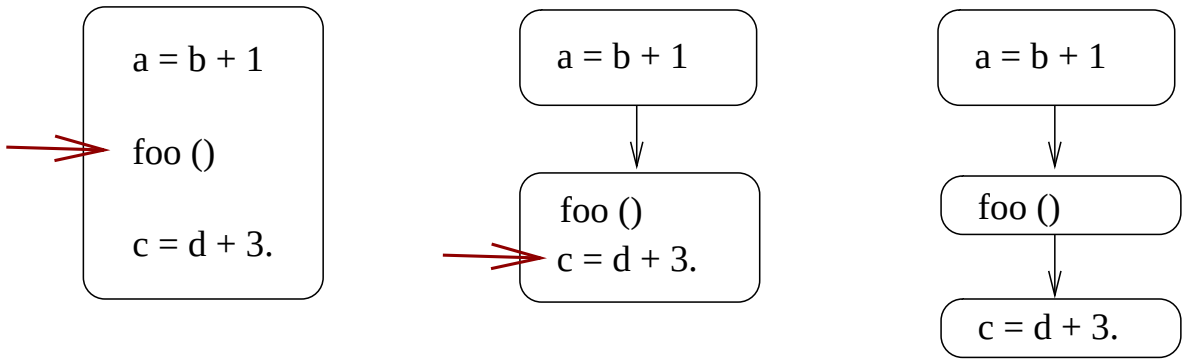


basic blocks of the SCoP

- contain only affine constructs, no side effects
- dominated by entry, postdominated by exit of the SCoP

Example: building SCoPs

- SCoPs built on top of the CFG:
- splitting basic blocks: split_block



basic blocks = containers
split basic blocks for:

- smaller code chunks
- reduce number of dependences
- moving parts of code around

SCoP Parameters

- parameters = variables varying outside a SCoP
  - function parameters
  - variables varying in outer loops
- context = constraints on parameters
  - use IPA info for bounding function parameters
  - use VRP's propagation engine

Analyses: scalars, arrays, dependences

GRAPHITE built on top of:

- scalar evolutions: number of iterations, access functions
- array and pointer analyses
- data dependence analysis
- scalar range estimations: undefined signed overflow, undefined access over statically allocated data, etc.

GRAPHITE : polyhedral representation for a SCoP

Statements + parametric affine inequalities

1. a domain = bounds of enclosing loops

```
for (i=0; i<m; i++)
 for (j=5; j<n; j++)
  A[2*i][j+1] = ...
```

$$\left[\begin{array}{ccccc} i & j & m & n & cst \\ \hline 1 & 0 & 0 & 0 & 0 \\ -1 & 0 & 1 & 0 & -1 \\ 0 & 1 & 0 & 0 & 5 \\ 0 & -1 & 0 & 1 & -1 \end{array}\right] \quad \begin{array}{l} i \geq 0 \\ -i + m \geq -1 \\ j \geq 5 \\ -j + n \geq -1 \end{array}$$

GRAPHITE : polyhedral representation for a SCoP

Statements + parametric affine inequalities

1. a domain = bounds of enclosing loops
2. a list of access functions

```
for (i=0; i<m; i++)
 for (j=5; j<n; j++)
  A[2*i][j+1] = ...
```

$$\left[\begin{array}{ccccc} i & j & m & n & cst \\ \hline 2 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 \end{array}\right] \quad \begin{array}{c} 2*i \\ j+1 \end{array}$$

GRAPHITE : polyhedral representation for a SCoP

Statements + parametric affine inequalities

1. a domain = bounds of enclosing loops
2. a list of access functions
3. a schedule = execution time (static + dynamic)

- sequence $[\![s_1; s_2]\!]$:

$$\begin{aligned} \mathcal{S}[\![s_1]\!] &= t \\ \mathcal{S}[\![s_2]\!] &= t + 1 \end{aligned}$$

- loop $[\![loop_1\ s\ end_1]\!]$: i_1 indexes $loop_1$ iterations: dynamic time

$$\begin{aligned} \mathcal{S}[\![loop_1]\!] &= t \\ \mathcal{S}[\![s]\!] &= (t, i_1, 0) \end{aligned}$$

CLooG: Code Generation

1. fill CLooG program structures: context, statement domains, scheduling functions
2. cloog_program_generate
3. cloog_clast_create
4. walk the AST, recompose a GIMPLE program:
   - modify loop structure
   - create_iv
   - reuse parts of lambda-code.c

GRAPHITE: Road Map

- select SCoPs
- lib integration PolyLib, CLooG, PiPLib, Omega
- extend lambda-code.c interface with CLooG
- cost models more static analyzers, and transform selection
- array regions improve data deps in interproc mode