Single-Path Code Generation and Input-Data Dependence Analysis

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Motivation

Uncertainty in program execution time

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T-CREST

Uncertainty in program execution time

Hardware

Duration of operations dependent on internal state

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Software

Different inputs lead to paths of varying execution time

The Single-Path Approach

- Singleton execution path
  - Reduce complexity of path analysis

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- Singleton execution path
  - Reduce complexity of path analysis
- Execution time stable w.r.t. varying input data
  - Known ET for a particular input
    $\Rightarrow$ Reasonable predictions for any input

The Single-Path Approach

Eliminate input-data dependent control flow.

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Predicated execution

```
(guard) instruction;
```

If-conversion

```
if (cond) {
  x = a + 1;
} else {
  x = b - 2;
}
```

```
( cond) x = a + 1;
(!cond) x = b - 2;
```

Single-Path Transformation Rules

- Rules to transform from high-level language to single-path sequence of predicated statements [Puschner et al., 2012]

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- Example: Treatment of loops

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while (cond)
  // max N times
  {
    stmts;
  }
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```
finished := false;
for i = 1 .. N {
  if (!cond)
    finished := true;
  if (!finished) {
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}
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- How to implement this in a compiler??

Single-Path Code Generation

Contributions

- Formulation of the single-path transformation on the CFG level

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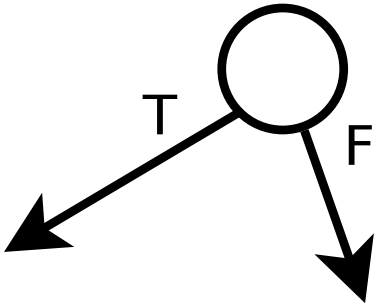
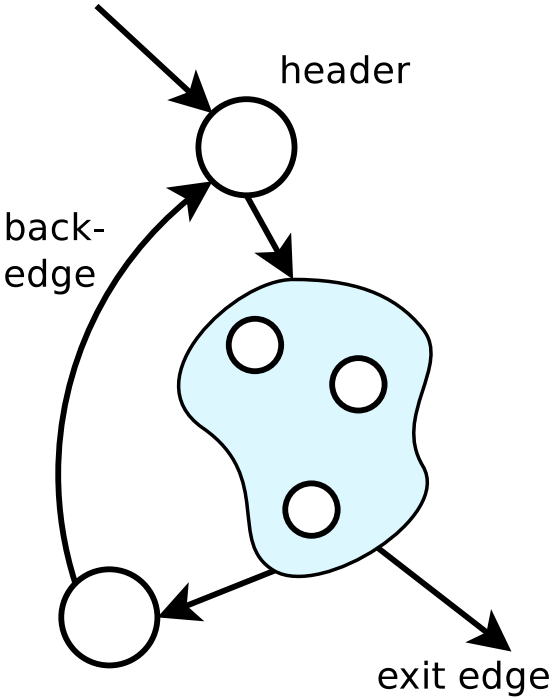
- Formulation of the single-path transformation on the CFG level
- Prototype implementation in a code generator (LLVM backend for Patmos)

Control-flow Graph



- Nodes with at most two successors
- Branch condition



- Reducible control flow graph

The Single-Path Graph Transformation

- Admissible paths in CFG: local loop bounds
- Predicated Nodes
- Semantic actions on predicates at nodes and edges

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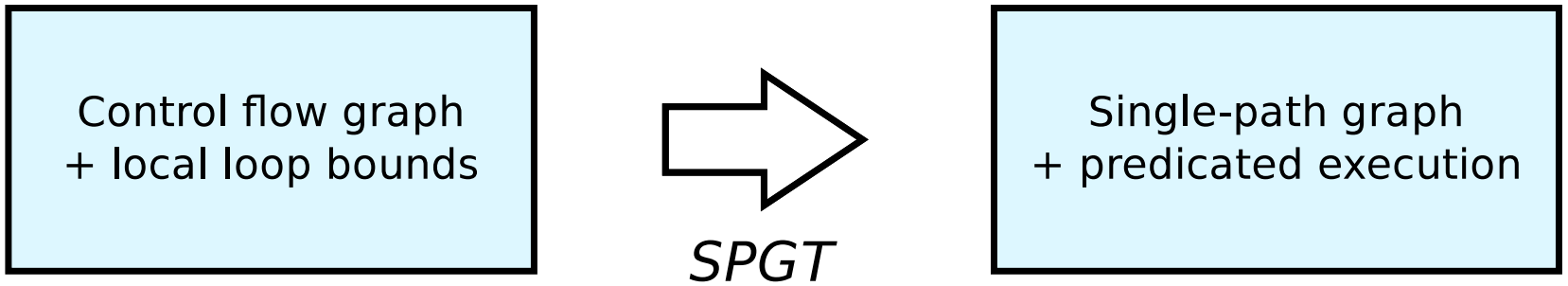
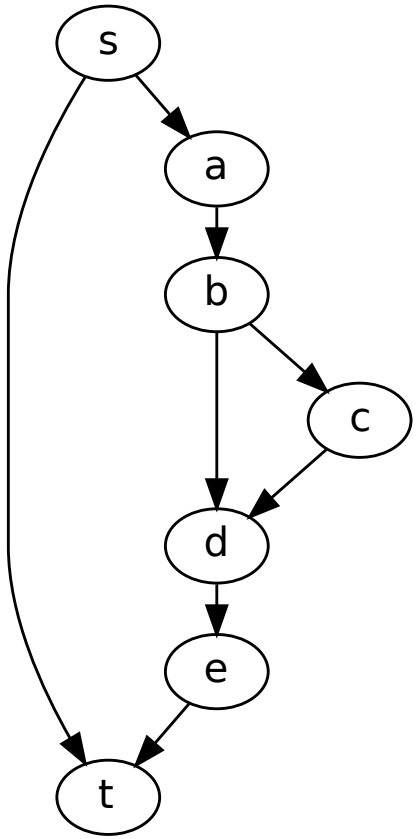


Acyclic regions

[Park and Schlansker, 1991] describe transformation in acyclic case



- Partitioning by Control Dependence

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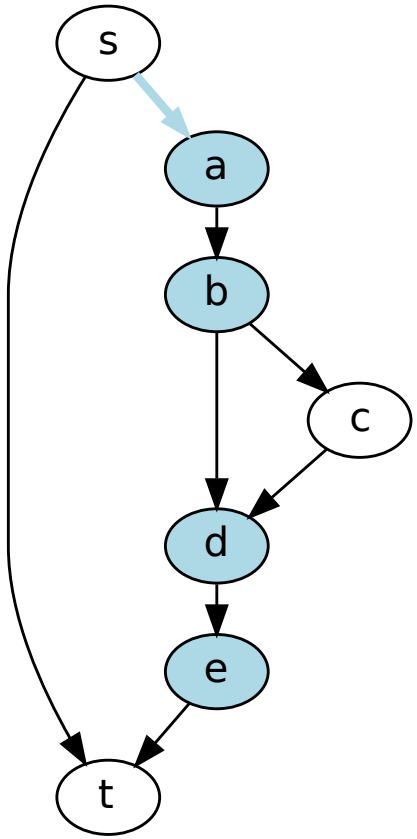

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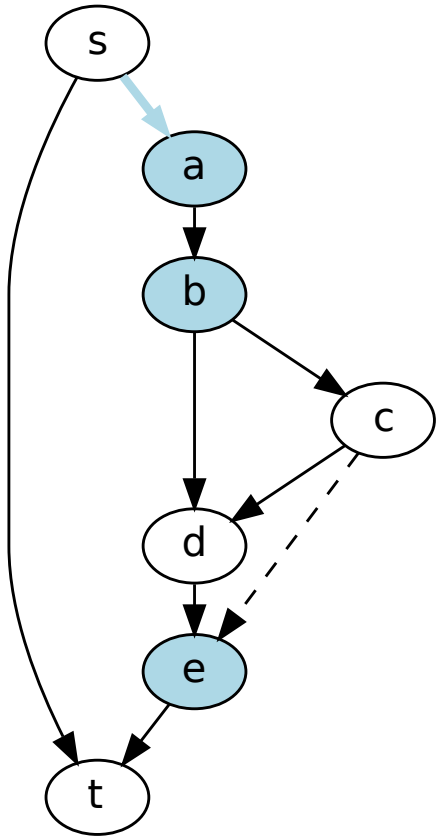

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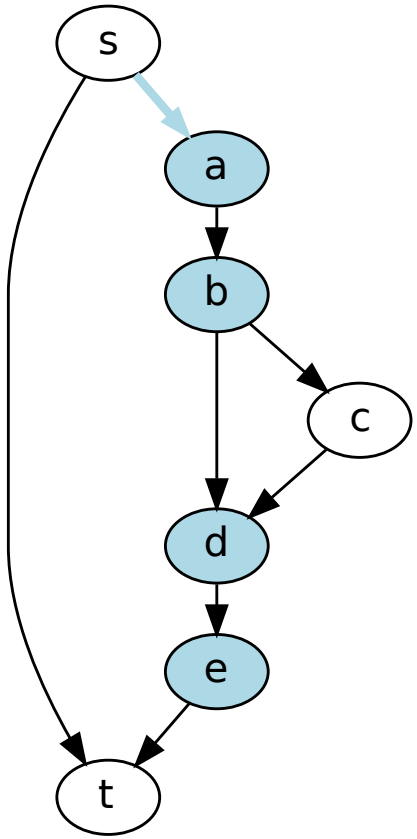
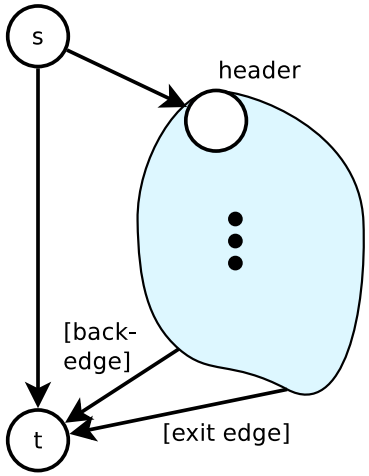


- Partitioning by Control Dependence
- Nodes with same set of CD: same predicate
- Predicate assignments at source of CD edges
- Initialization with *false*
- Topological sort order

Loops



- Forward control flow graph of loop nodes
- Nested inner loops compacted into single node
- Proceed as in acyclic case

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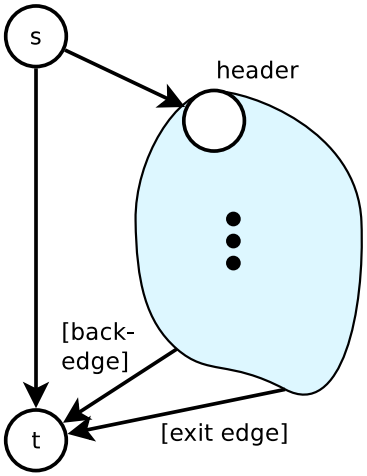

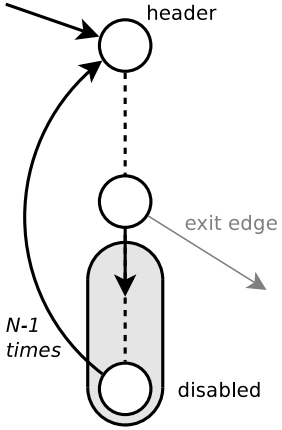

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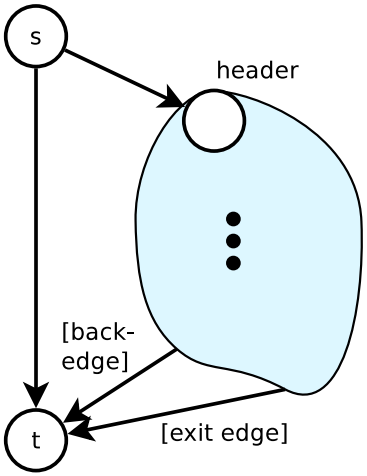

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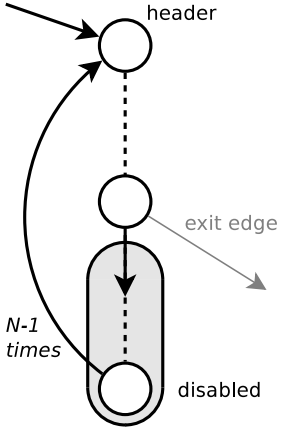

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Recursive composition of the SP-Graph starting from outermost (pseudo-) loop

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- Determine input-data dependent branch conditions

- Input data dependency
  - Definition based on Thinned Gated Static Assignment (TGSA) form
  - γ-instructions, μ-instructions, η-instructions capture various types of dependencies
  - From TGSA, input-data dependency graph is constructed
  - Path from $x \rightarrow y$: x may depend on y, otherwise x is independent from y

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Implementation

- Prototype implementation in Patmos backend (LLVM)

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- Patmos features . . .
  - A fully predicated instruction set
  - 7+1 predicate registers that can be stored/restored at once
  - Explicitly managed local memories

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Summary

- Single-path conversion as transformation on CFGs
- Prototype implementation in Patmos backend

http://github.com/t-crest/

References I

Park, J. C. and Schlansker, M. (1991).
On predicated execution.
Technical report, Hewlett Peckard Software and Systems Laboratory.

Puschner, P., Kirner, R., Huber, B., and Prokesch, D. (2012).
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