

Exploiting Branch Constraints without Exhaustive Path Enumeration



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Static WCET Analysis

- Flow analysis
 - Loop bounds and infeasible paths
- Micro-architectural modeling
 - Effects of micro-architecture on execution time
- Estimation
 - Find an upper bound on WCET given the results of flow analysis and micro-architectural modeling

WCET Estimation

- Tree-based: Timing schema
 - Simple and efficient
 - Difficult to handle infeasible path information
- Implicit path enumeration (IPET)
 - Program flows expressed as linear equations
 - Generally difficult to express infeasible path consisting of a sequence of basic blocks
- Path-based
 - Search for the longest path in the program
 - Naturally handles various flow information

Longest Path Search

- Enumerate all possible paths and select the one with the maximum execution time
 - 6.55×10^{16} paths in a single iteration of a loop
 - Fails to produce results after 60 hours
- Stappert's technique
 - Find the longest path π
 - If π is infeasible remove π from the CFG and search for the next longest path
 - Inefficient if large fraction paths are infeasible
 - 99.9% infeasible paths
- How to avoid exhaustive path enumeration?

Overall approach

- ❑ WCET of each basic block is known
- ❑ Focus on the loops
- ❑ Construct DAG corresponding to loop body
- ❑ Acyclic path from source to sink in DAG
- ❑ Find the longest acyclic path in the DAG

Avoiding exhaustive path enumeration

- Compute the “conflicting” branch-branch or assignment-branch pairs a-priori
 - $x > 3$ and $x < 2$ are conflicting
 - $x = 1$ and $x > 2$ are conflicting
- Traverse the DAG from sink to source
- Remembering the longest path so far is not enough during traversal
 - If it is infeasible, then we need to backtrack
- Maintain only those partial paths which when extended can potentially become the longest path

Illustration: Infeasible Path

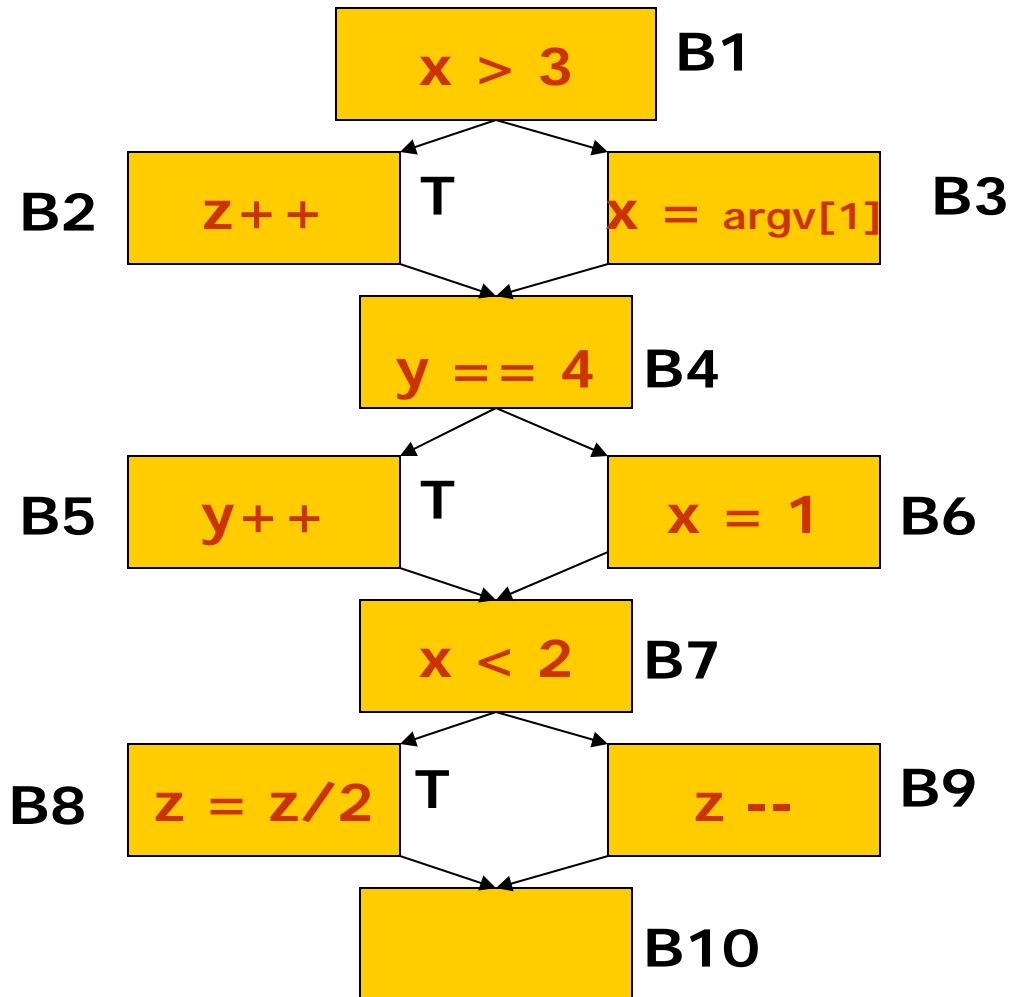
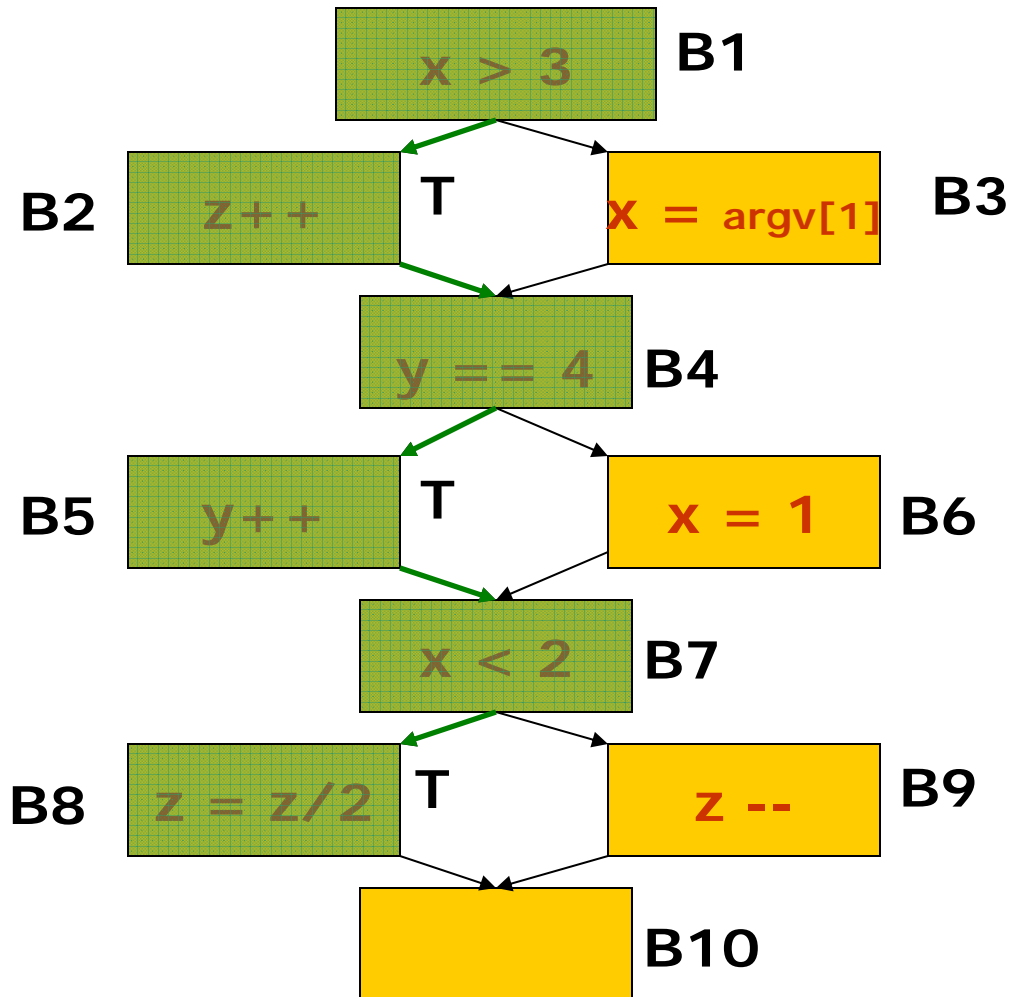


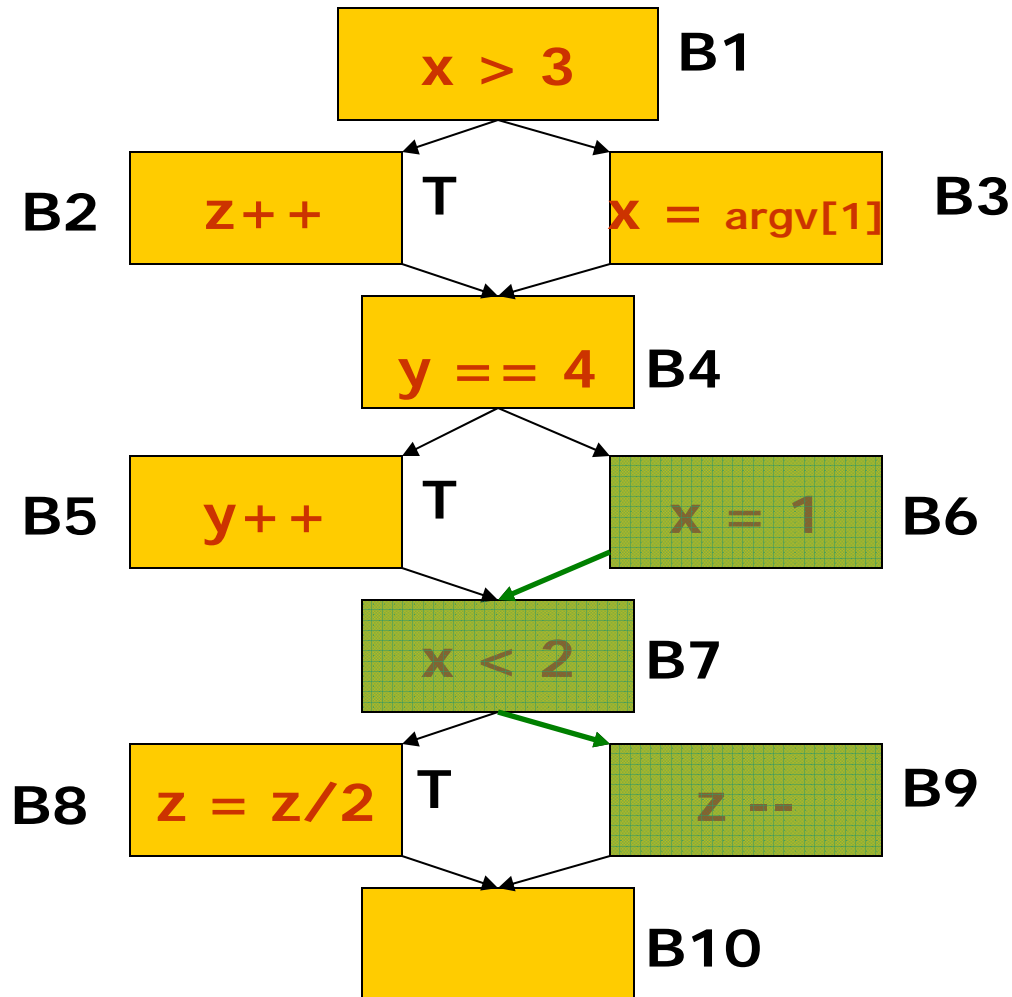
Illustration: Infeasible Path



Conflicting pairs:

$B1 \rightarrow B2$ & $B7 \rightarrow B8$

Illustration: Infeasible Path

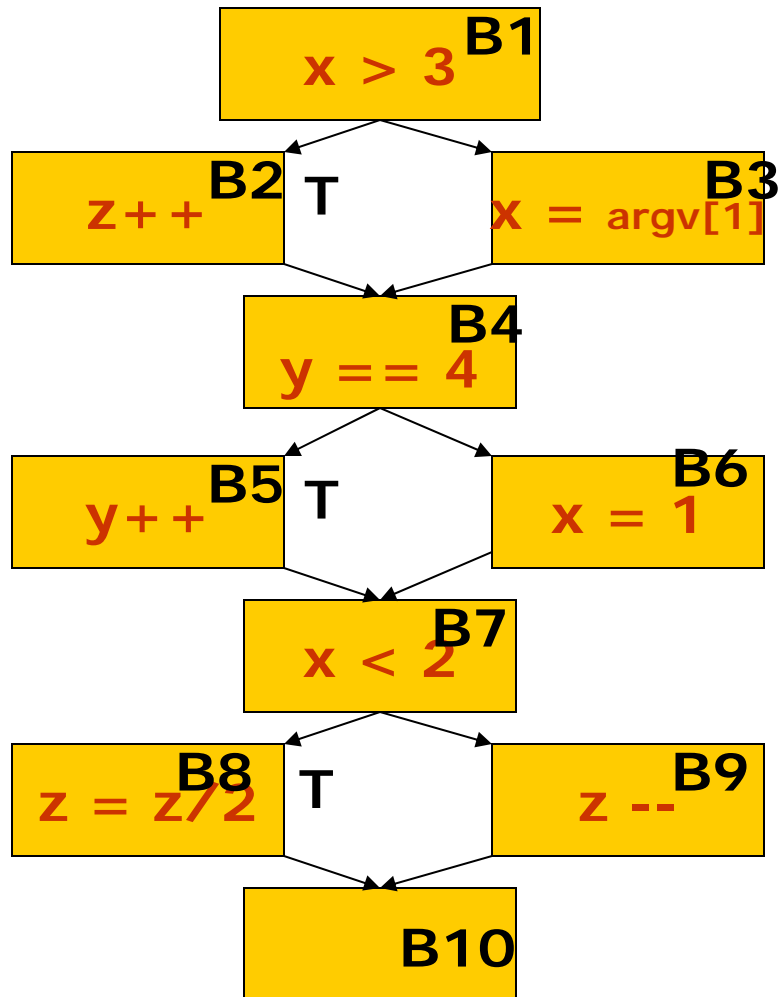


Conflicting pairs:

$B1 \rightarrow B2$ & $B7 \rightarrow B8$

$B6 \rightarrow B7$ & $B7 \rightarrow B9$

Illustration: WCET Estimation



Conflicting pairs:
B1 → B2 & B7 → B8
B6 → B7 & B7 → B9

B10: B10

B9: B9, B10

B8: B8, B10

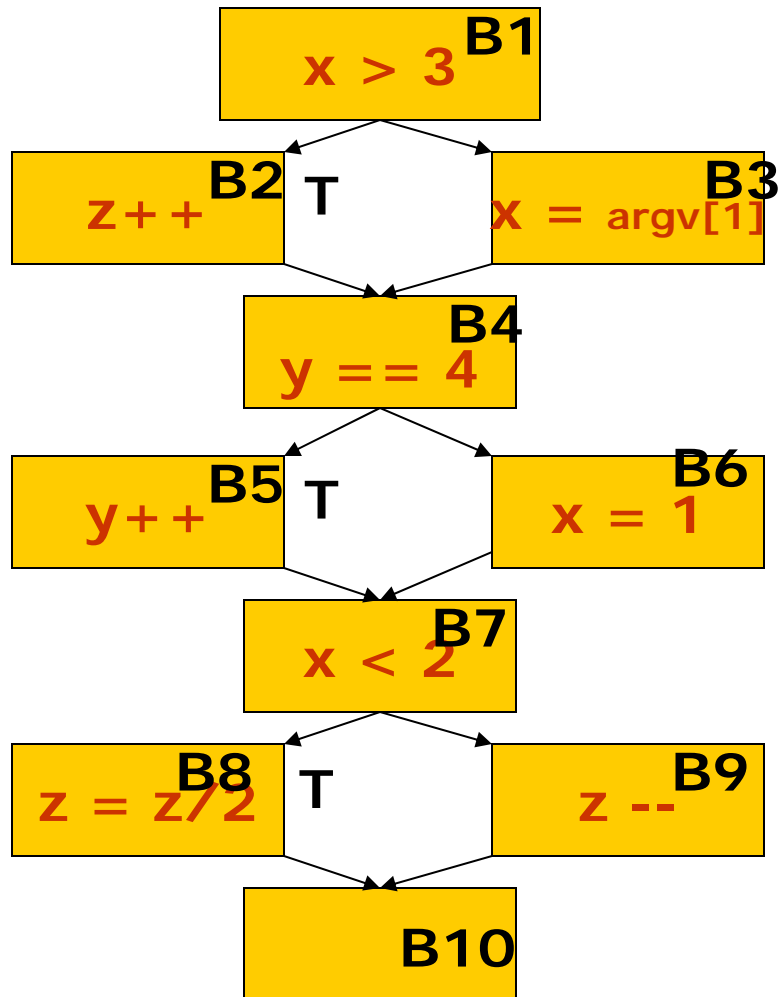
B7: B7, B8, B10 [B7→B8]

: B7, B9, B10 [B7→B9]

~~B6: B6, B7, B8, B10 [B7→B8]~~

~~: B6, B7, B9, B10 [B7→B9]~~

Illustration: WCET Estimation



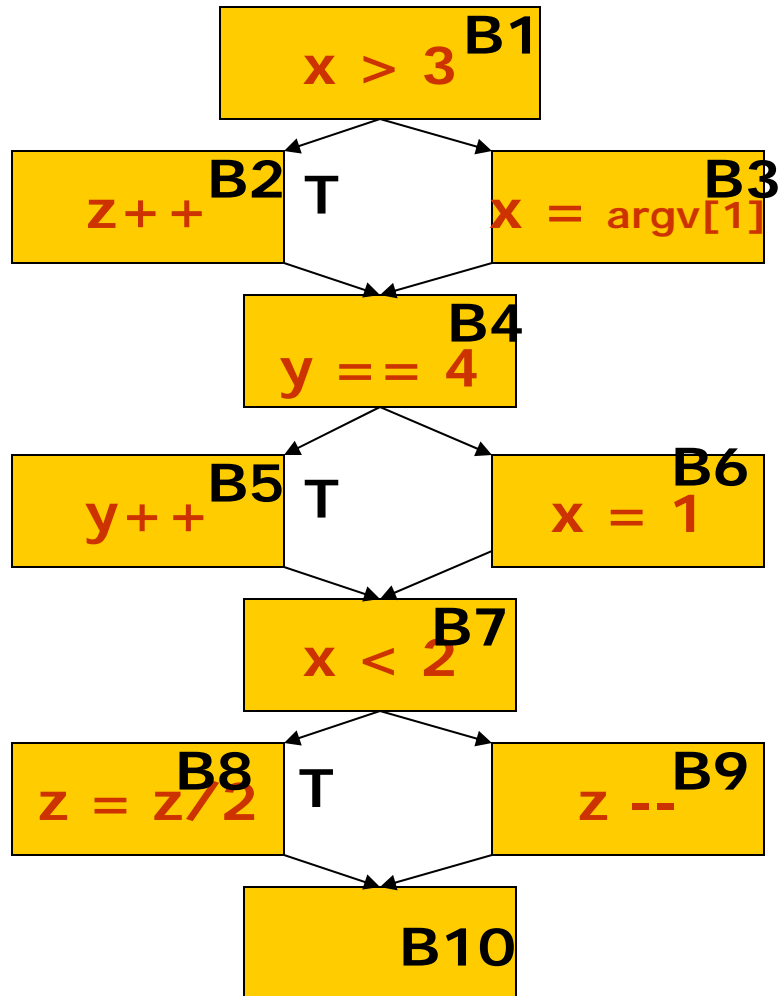
Conflicting pairs:
B1 → B2 & B7 → B8
B6 → B7 & B7 → B9

B7: B7, B8, B10 [B7→B8]
: B7, B9, B10 [B7→B9]

B6: B6, B7, B8, B10

B5: B5, B7, B8, B10 [B7→B8]
: B5, B7, B9, B10 [~~B7→B9~~]

Illustration: WCET Estimation

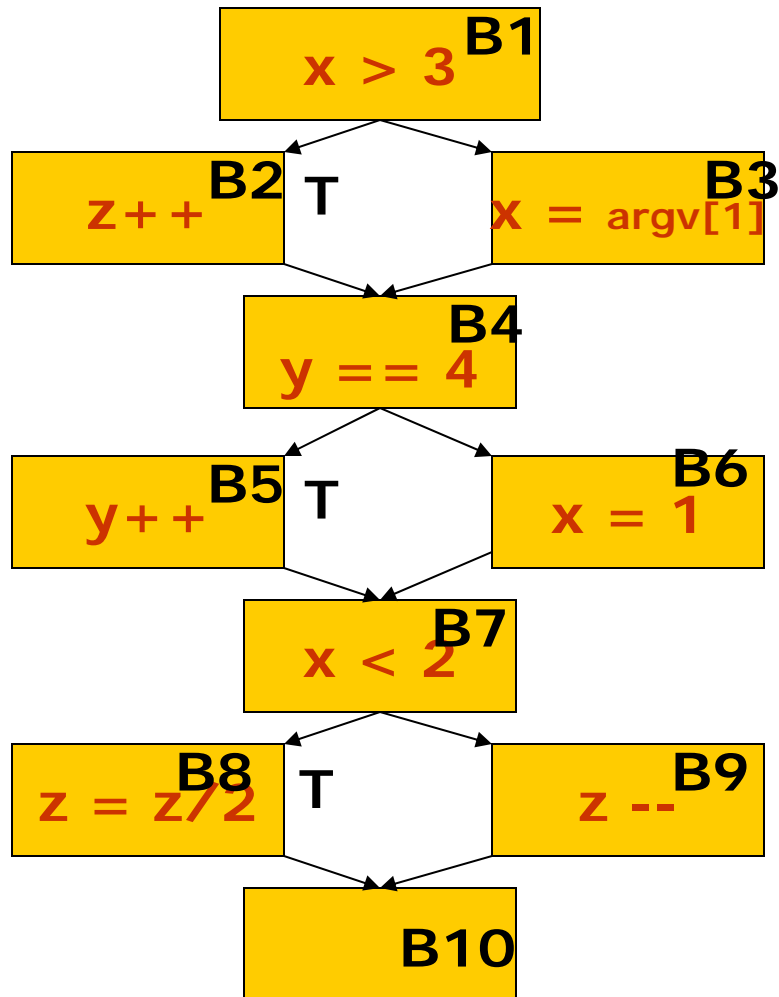


Conflicting pairs:
 $B1 \rightarrow B2$ & $B7 \rightarrow B8$
 $B6 \rightarrow B7$ & $B7 \rightarrow B9$

$B6: B6, B7, B8, B10$

$B5: B5, B7, B9, B10$

Illustration: WCET Estimation



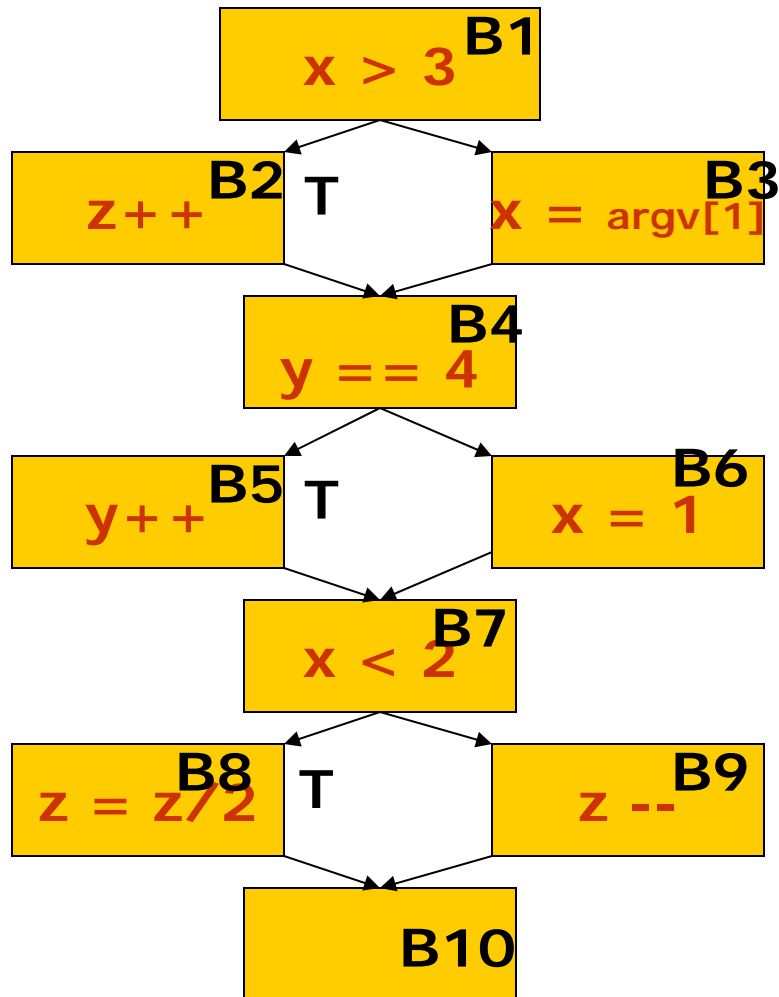
Conflicting pairs:
B1 → B2 & B7 → B8
B6 → B7 & B7 → B9

B7: B7, B8, B10 [B7 → B8]
: B7, B9, B10 [B7 → B9]

B6: B6, B7, B8, B10

B5: B5, B7, B8, B10 [B7 → B8]
: B5, B7, B9, B10 [~~B7 → B9~~]

Illustration: WCET Estimation



Conflicting pairs:
B1 → B2 & B7 → B8
B6 → B7 & B7 → B9

B6: B6, B7, B8, B10

B5: B5, B7, B8, B10 [B7 → B8]
: B5, B7, B9, B10

Experimental Evaluation

Function	Total Paths	Feasible Paths	Enumerated Paths
statemate	6.55×10^{16}	1.09×10^{13}	121,831
statemate1	19,440	7,440	15
statemate2	902	36	14
statemate3	1,459,364	69,867	40
statemate4	10	10	1
statemate5	256	58	4

Discussion

- ❑ Infeasible path patterns of arbitrary length
- ❑ Discovering more infeasibility information
- ❑ Infeasible paths spanning loop iterations