Dynamic Code Coverage using dyninstAPI

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Outline

- Motivation
- Extension to dyninstAPI
- Using Dominator Tree
- Code Coverage Algorithm
- Current Status
- Experiments and Results
- Conclusion and Contribution

Motivation

- Code Coverage is useful for ensuring bug-free software
  - identifying source code lines not executed in a run or runs
  - making sure that each path is taken at least once during the testing phase
- Useful for identifying bottlenecks in basic block level
- Dynamic approach will produce faster code coverage results for long running programs

Extension to dyninstAPI

- New classes added to dyninstAPI
  - BPatch_basicBlock
  - BPatch_sourceBlock
  - BPatch_flowGraph
- Arbitrary Instrumentation points
  - Conservative base trampoline
- Base trampoline deletion

class BPatch_basicBlock

- machine code basic block
- contains information
  - start/end address of the block in executable
  - outgoing/incoming edges to/from other basic blocks
  - corresponding source code line information
  - immediate dominator and basic blocks dominated immediately
  - delay instruction included if exists
- creation is machine dependent
  - machine specific functions/classes for machine independence

class BPatch_sourceBlock

- source code segment corresponding to a machine basic block
- contains set of corresponding source line numbers
- created one for each machine basic block

Arbitrary instrumentation points

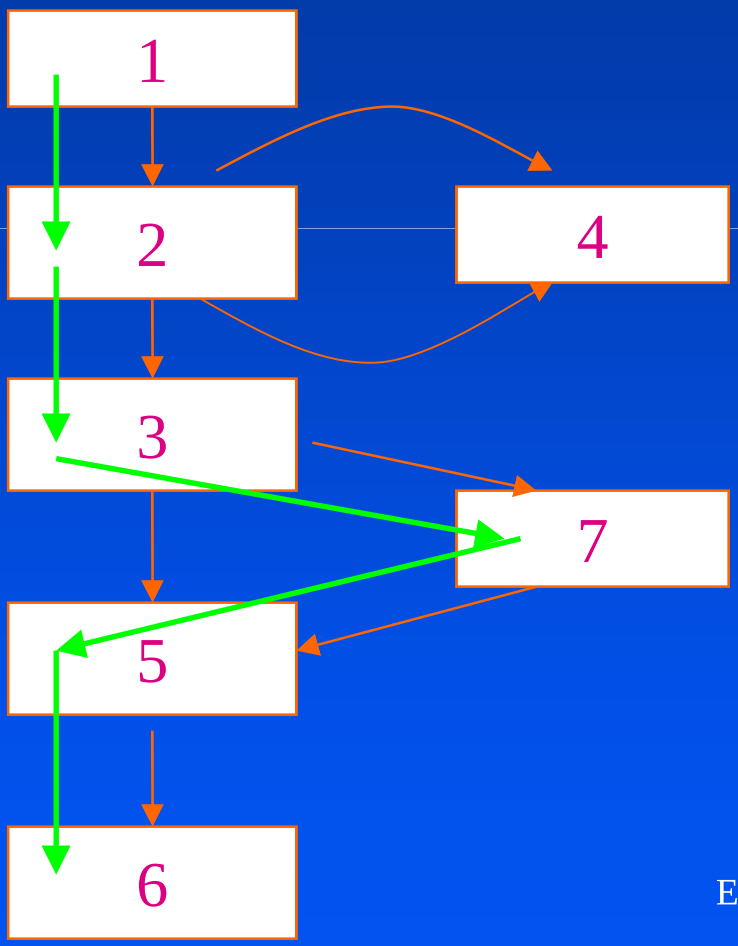
- Code Coverage needs basic block level instrumentation
  - dyninstAPI used to support function level instrumentation for sparc-solaris
  - added arbitrary instrumentation points for SPARC
- More state must be maintained in base trampolines
  - save/restore condition codes before/after arbitrary instrumentation points
  - Sparc arch supports user mode condition-code write/read for version v8plus and later

Using dominator tree

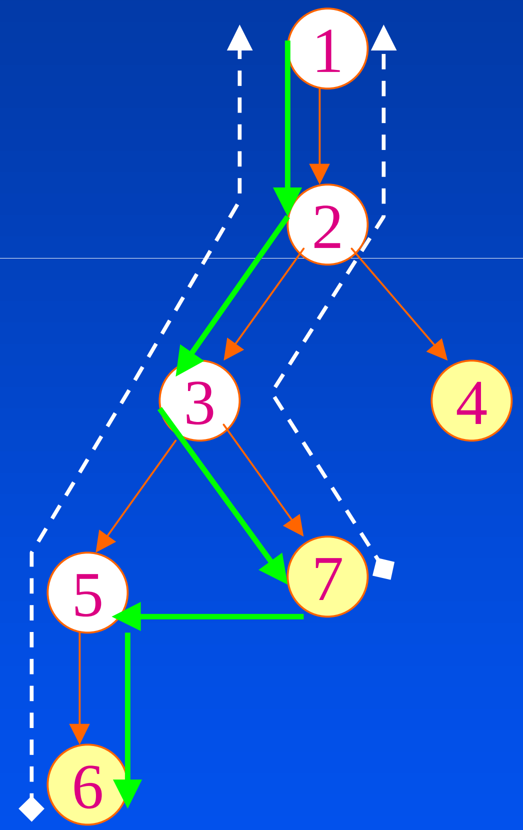
- Definitions
  - A **dom** B if all paths from entry to B goes through A
  - A **idom** B if (C != A) and (C dom B) implies (C dom A) for all C
  - dominator tree built using the **idom** relation
- Fact
  - execution of leaf node in dominator tree guarantees execution of all basic blocks along the path from root node

Instrumenting leaf nodes

CFG



Dominator Tree

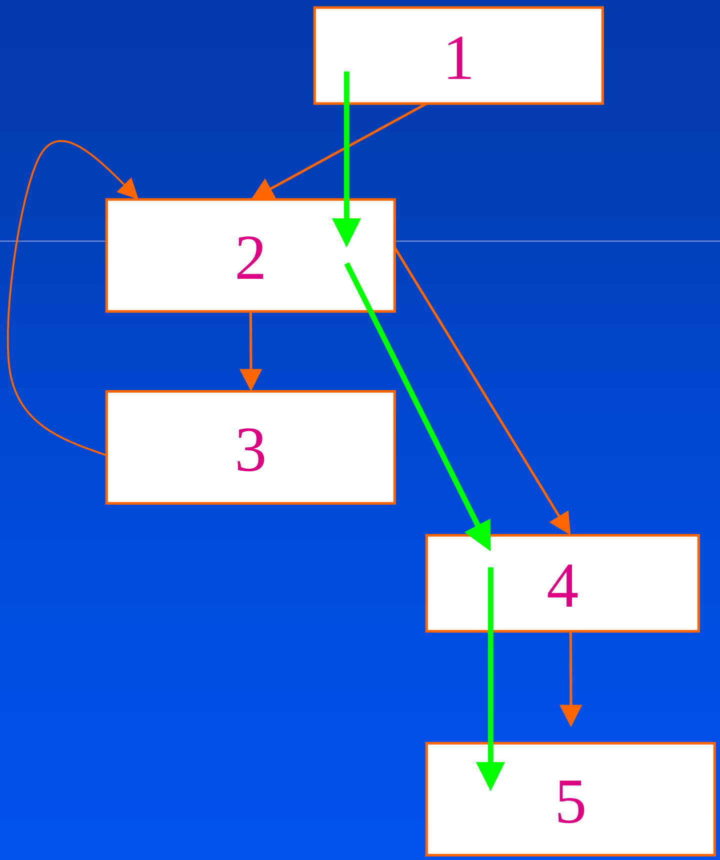


Executed:1, 2, 3, 5, 6, 7 Unexecuted: 4

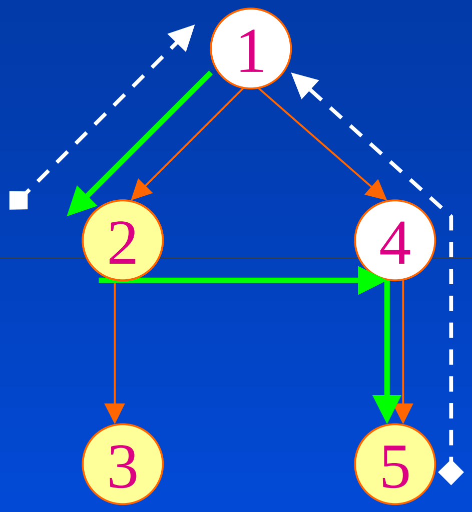
* instrument basic blocks that are leaf nodes in dominator tree

Instrumenting non-leaf node

CFG



Dominator Tree



Incorrect : Executed : 1, 4, 5   Unexecuted: 2, 3

Correct : Executed : 1, 2, 4, 5   Unexecuted: 3

* instrument basic blocks that have outgoing edge(s) to basic blocks not dominated by them

Code Coverage Algorithm

- Pre Run Phase
  - build CFG for each function
  - fill dominator info for CFG graph
  - choose basic blocks to instrument
  - assign a boolean variable to each basic block
  - at entry point to CFG set all variables to **false**
  - at the beginning of each basic block set its flag to **true**
  - use exit callback to record results

Code Coverage Algorithm(cont'd)

- Post Run Phase
  - at program termination for each basic block instrumented
    - read its variable
    - propagate the value up dominator tree
  - print the source code line numbers for the executed basic blocks
    - working on an improved UI

Dynamic Deletion

- Each Block Requires:
  - an instrumentation point with a base trampoline
  - each instrumentation point has a mini tramp
  - jump/call instructions
    - from mutatee address space to base tramp
    - from base tramp to mini tramp
- This is expensive for hot blocks!
- Once a block runs, don't need the code

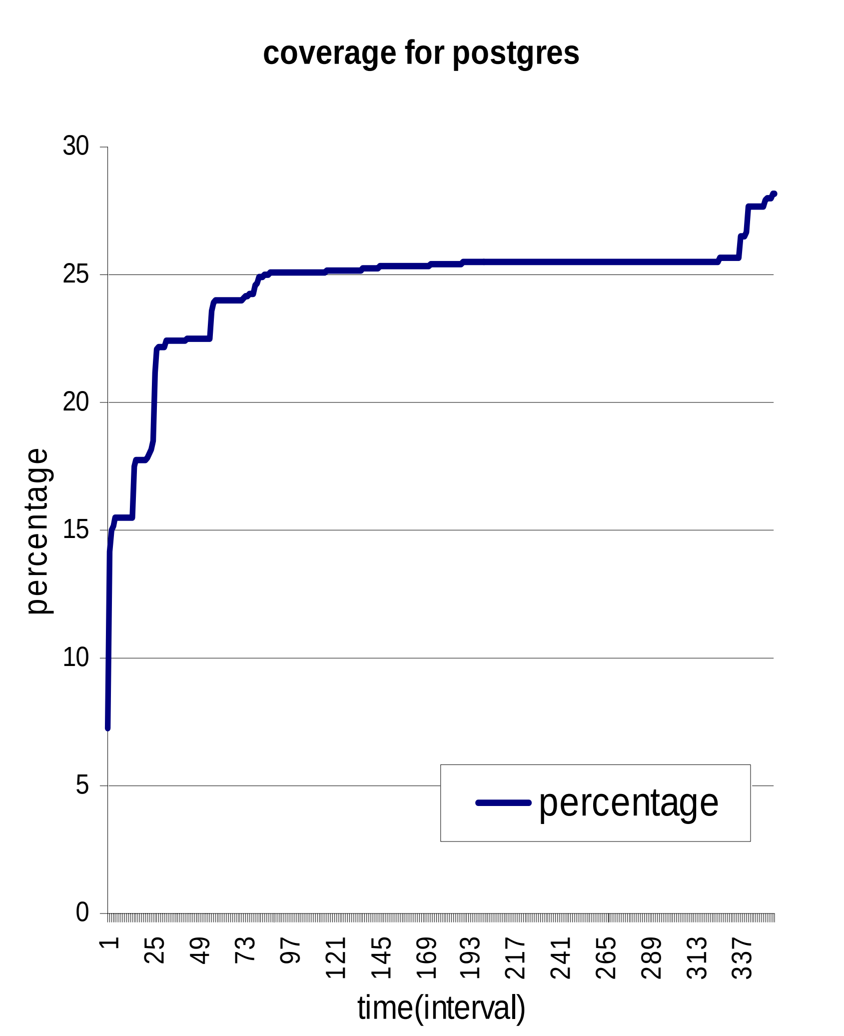
Instrumentation Code Deletion Policies

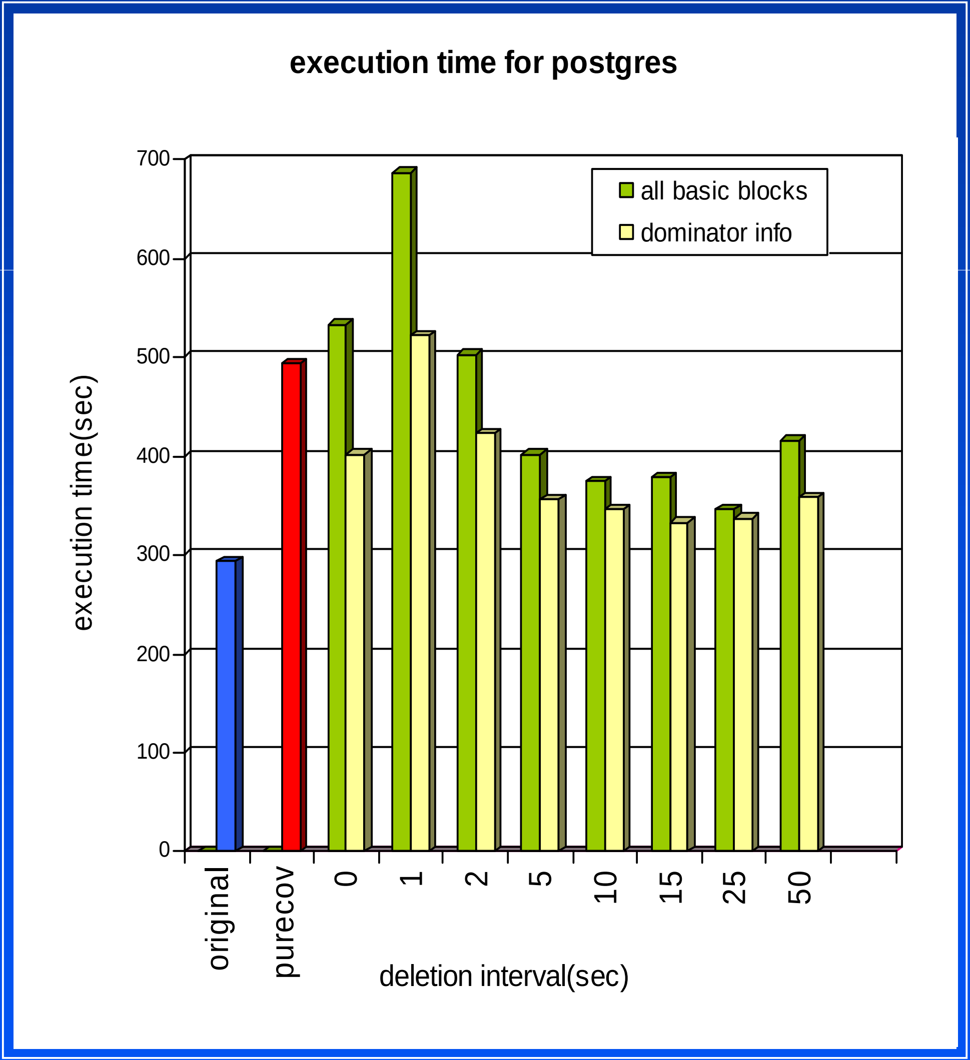
- Possible policies
  - at fixed time intervals given as parameter
  - first time it is executed
  - based on a cost-model
    - if inside a loop, how many times it will be executed, what the nest is, etc.
    - cost of deletion versus cost of execution
- We delete at fixed time intervals
  - stop the execution of mutatee
  - propagate information and delete instrumentation code for executed basic blocks

Current Status

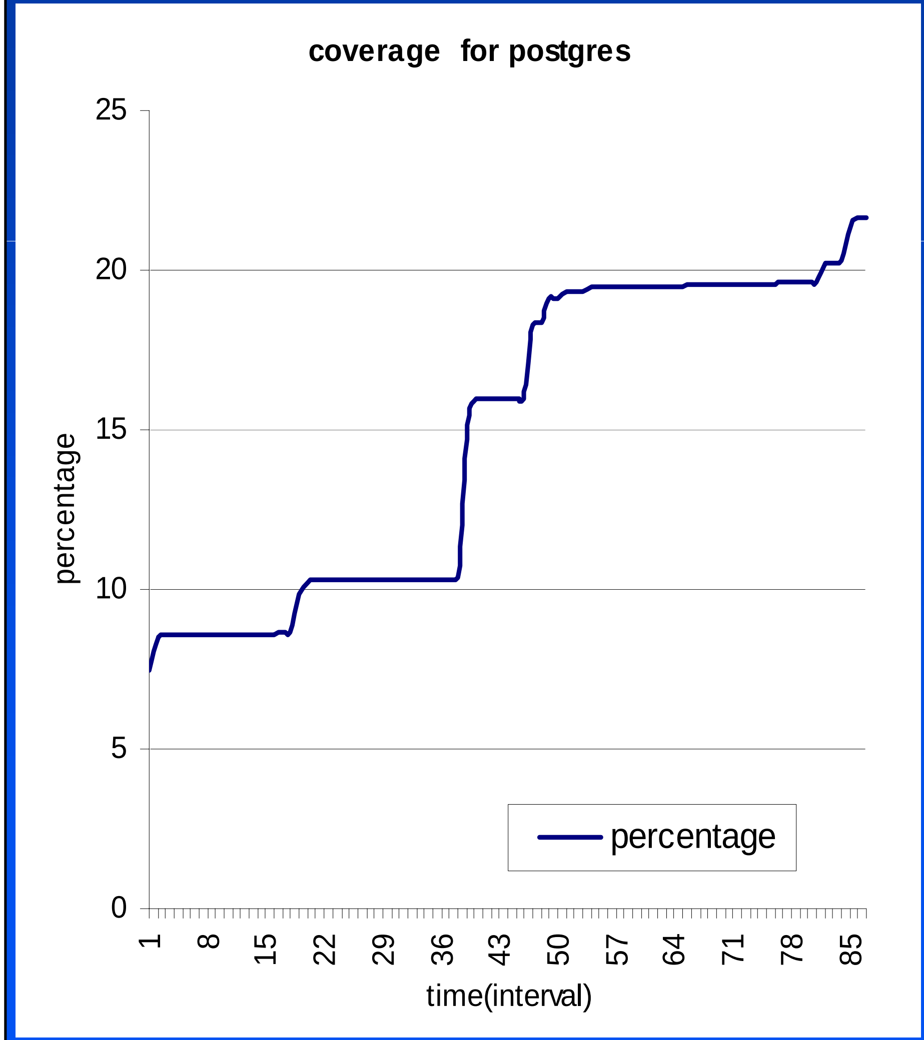
- Fully implemented on sparc-solaris platform
- Works for executables compiled with gnu-C and native-C compilers
- Tested on
  - PostgreSQL object-relational DBMS
  - SPEC95/CINT spec benchmark in C
    - 099.go 124.m88ksim 126.gcc 129.compress
    - 130.li 132.ijpeg 134.perl 147.vortex

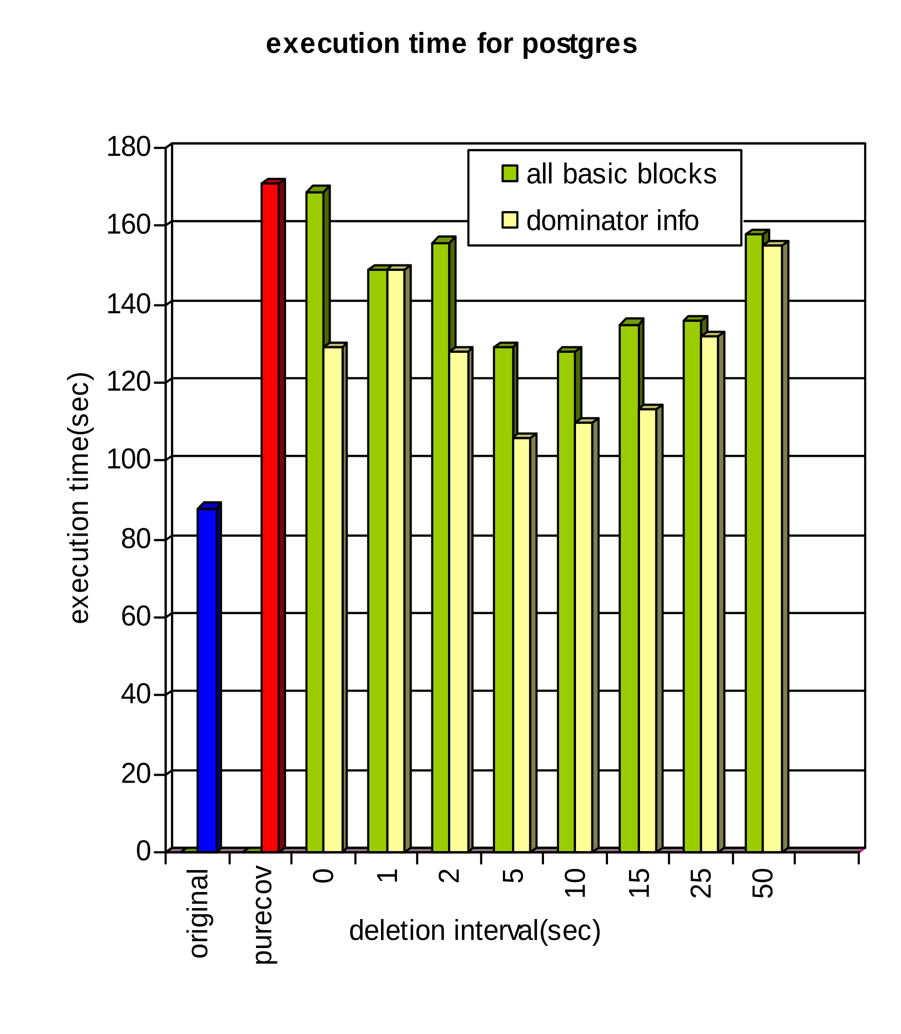
Postgres with crash-me benchmark



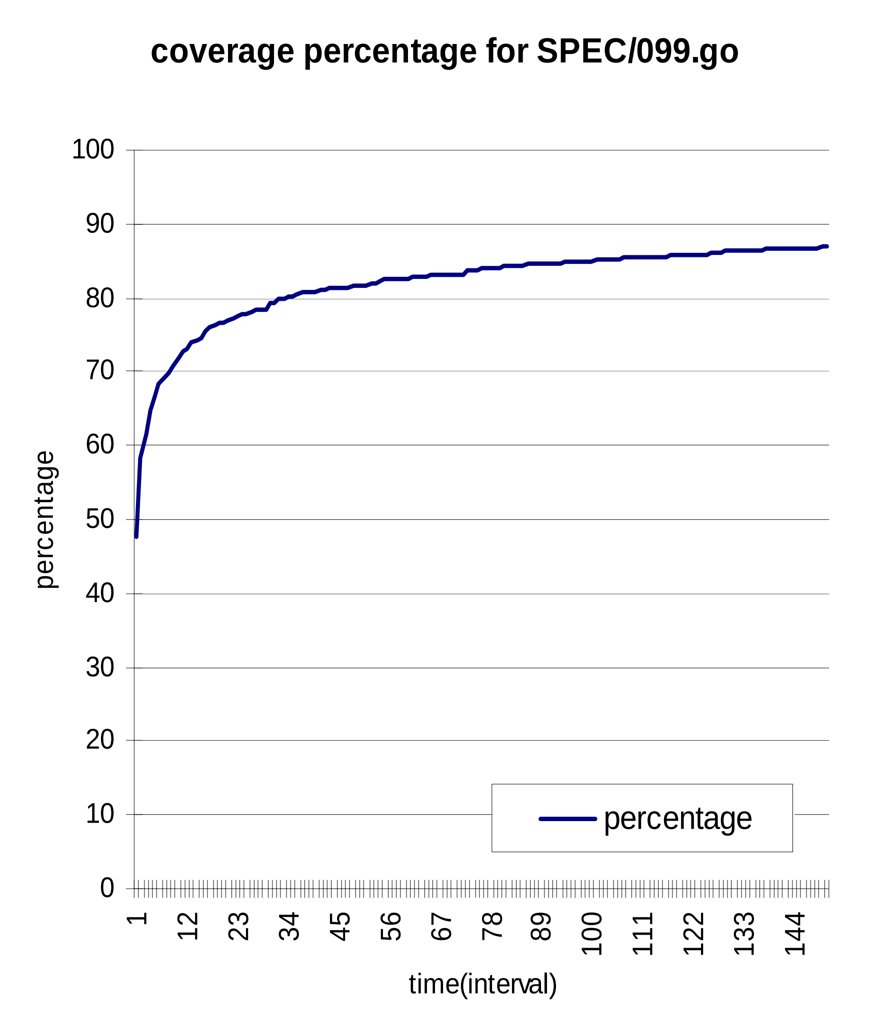


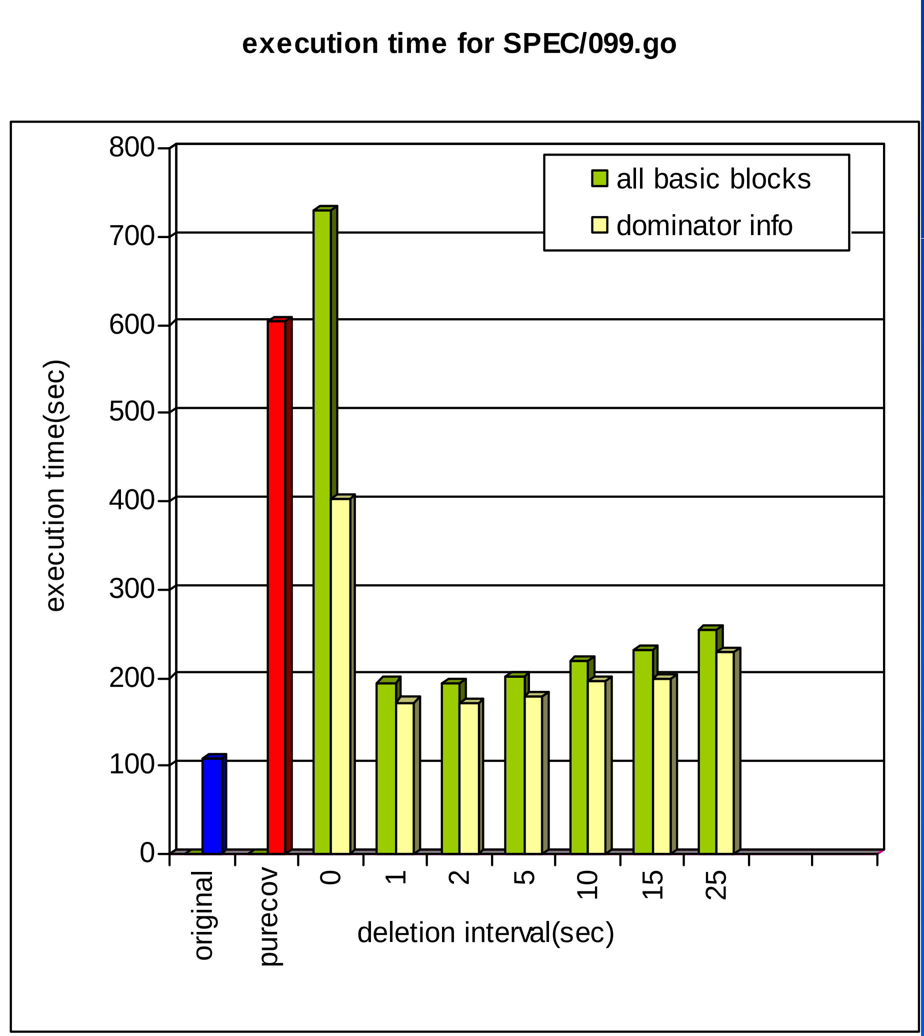
Postgres with wisconsin benchmark





SPEC95/099.go results





Total & Instrumented Basic Block Count

- Using dominator information reduces the total number of basic blocks instrumented by 35-50%

	Total number of Basic Blocks	Instrumentation count		Reduction Percentage %
		Leaf	Non-leaf	
Postgres	**45028**	**22956**	**3350**	**46.1**
099.go	**11233**	**4571**	**1916**	**42.3**
124.m88ksim	**5708**	**2831**	**546**	**40.8**
126.gcc	**68448**	**28911**	**13866**	**37.5**
129.compress	**269**	**126**	**12**	**48.7**
130.li	**2532**	**1229**	**223**	**42.7**
132.ijpeg	**5670**	**2626**	**357**	**47.4**
134.perl	**13181**	**6695**	**1432**	**38.3**
147.vortex	**19047**	**8137**	**4442**	**34.0**

Conclusion

- Using dominator tree information
  - reduces number of inst. points by 35-50%
  - frequently outperforms **purecov**'s execution
    - **purecov** slows down execution up to 10 times
- Using all basic blocks also outperforms purecov's execution for some values of deletion interval
- Deletion of instrumentation code produces faster code coverage results

Contribution

- Dynamic code insertion and deletion
  - existing code coverage tools use static code editing during/after compilation
  - instrumentation code is executed even though no extra information is produced
- Usage of dominator tree to reduce number of instrumentation
- Faster code coverage results for long running programs
- Less overhead for programs which have
  - Many infrequently executed paths
  - Many frequently executed paths