Runtime Program Evolution

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Motivation

- Software systems are
  - becoming more complex
  - being built from component parts
  - running in complex and varied environments
- Tools are required to
  - understand the behavior of such systems
  - react to changing environments
  - manage software components

dyninstAPI

- API for runtime code patching
  - new code can be added to a program while it executes
  - permits instrumentation and modification of programs
- Provides processor independent abstractions
  - same patching can be applied to multiple systems
- Includes meta-instrumentation
  - tracks overhead on inserted code

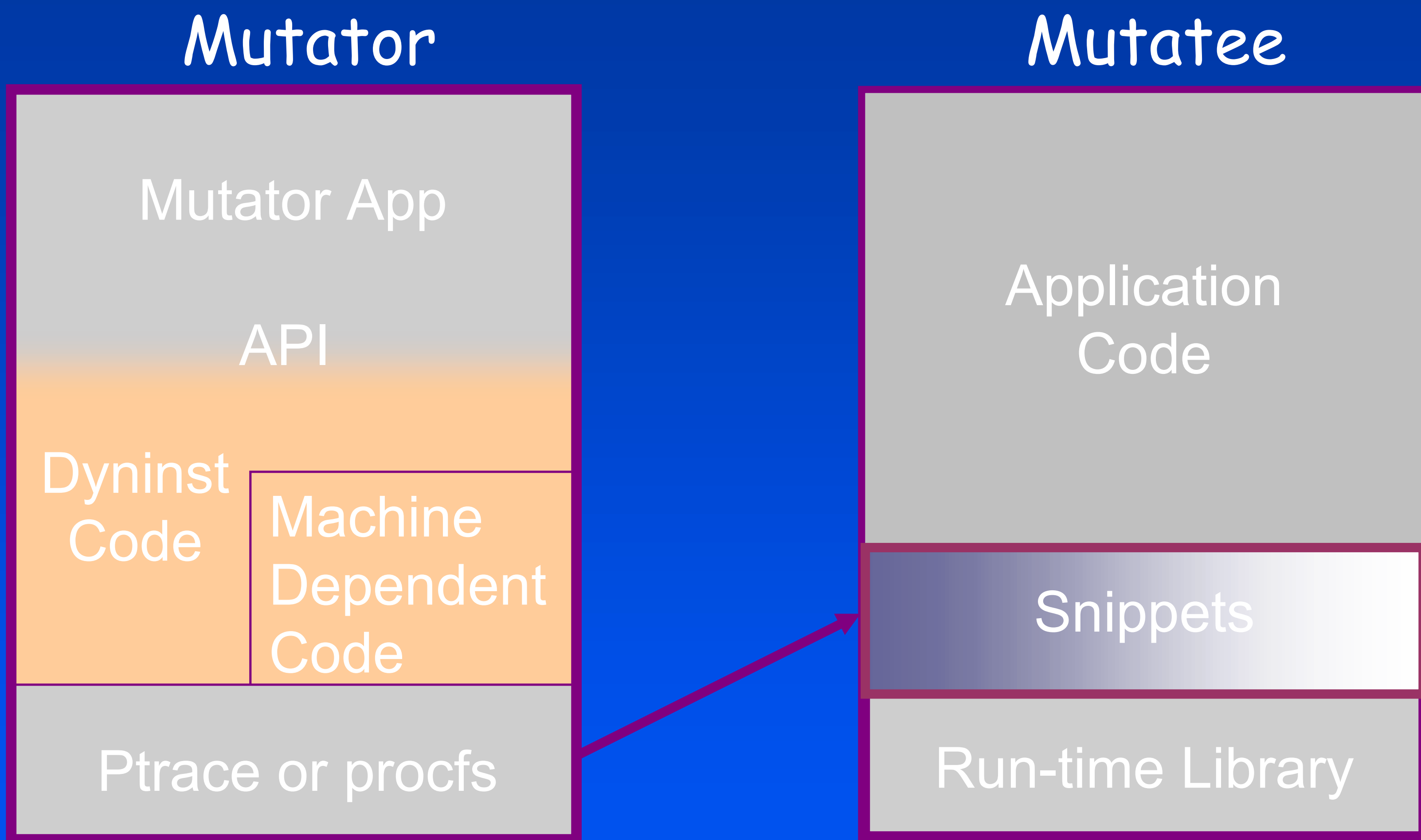
Applications of Runtime Code Patching

- Performance measurement
  - Recording application behavior
- Correctness debugging
  - Fast conditional breakpoints
  - Data breakpoints
- Execution driven simulation
  - Architecture studies
- Testing
  - Code coverage testing
  - Forcing hard to execute paths to be taken

Advantages of Runtime Code Patching

- No forethought needed
  - No user inserted probes
  - No special compiling or linking
  - Start anytime during execution
- Only insert code when needed
  - No wasted checks for "disabled" code
  - Can add new code during execution

Structure of the Dyninst Library



API Library

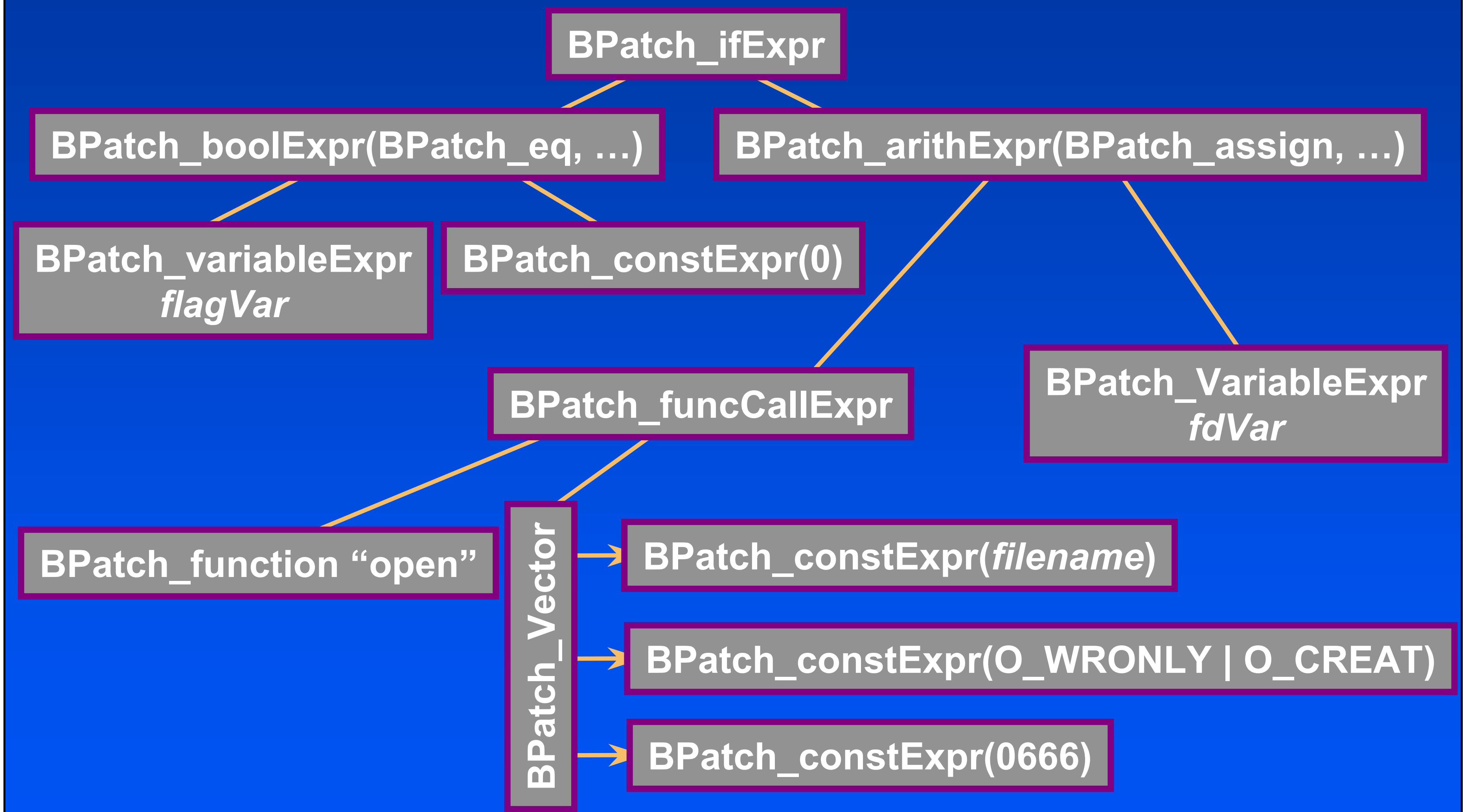
- Provides:
  - Functions for control of mutatee
  - Runtime code generation
  - Information about mutatee
- A set of C++ classes
  - Bpatch_thread
  - BPatch_image
  - BPatch_snippet
  - BPatch_variableExpr
  - BPatch_block

Representing Code Snippets

- Platform Independent Representation
  - Same code can be inserted into apps on any system
- Simple Abstract Syntax Tree
  - Can refer to application state (variables & params)
  - Includes simple looping construct
  - Permits calls to application subroutines
- Type Checking
  - Ensures that snippets are type compatible
  - Based on structural equivalence
    - allows flexibility when adding new code

Snippet Example

if (flagVar == 0) fdVar = open(filename, ...)



Type Support in Dyninst

- Access to local (stack) variables
- Complex types
  - non-integer scalars
  - structures
  - arrays
- Correctness debugging
  - print contents of data structures

Implementation

- Use Compiler debugger info (stab records)
  - access to user defined types
  - information about local variables
  - type information for all variables
  - line number to text segment address mapping
- Incremental parsing
  - parse stabs for a module on first use
- dyninst User can define types
  - allows the creation of new types for patched code
  - permits reconstruction of stripped symbols

API Example

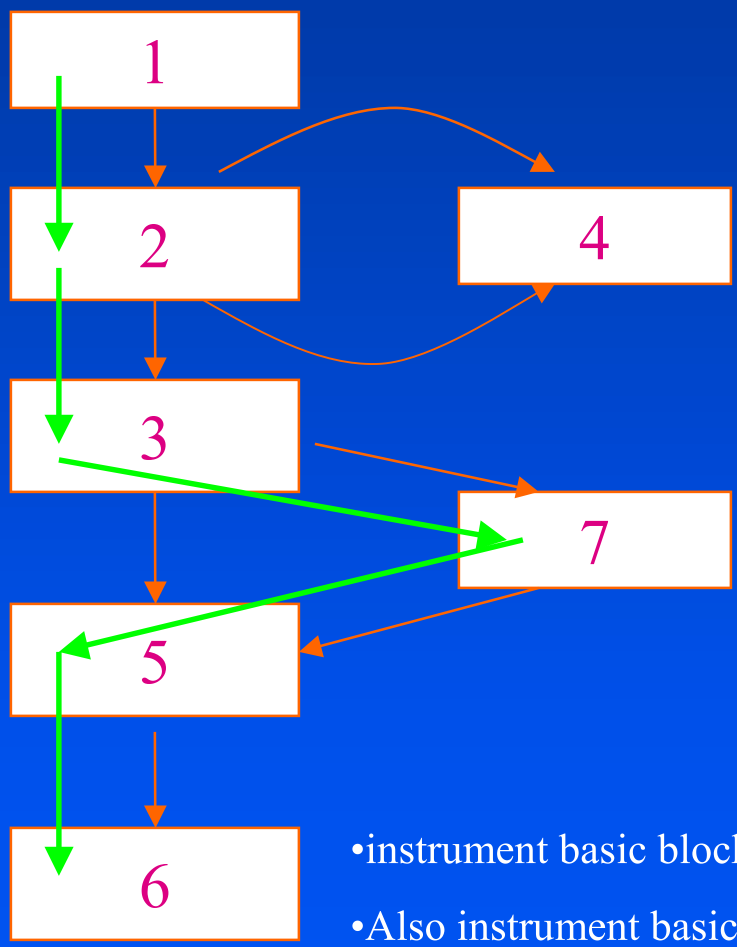
```
// find all variables defined in an image
BPatch_Vector<BPatch_variableExpr *> vars =
   appImage->getGlobalVariables()

for (i=0; i < vars->size(); i++) {
   BPatch_variableExpr *v = (*vars)[i];
   switch (v->getType()->type()) {
       case BPatch_scalar:
          printf("%s is a scalar of type %s\n", v->getName(),
                 v->getType()->getName());
       case BPatch_structure:
          FieldVector *fields = v->getType()->getComponents();
          for (j=0; j < fields->size(); j++) {
                 Bpatch_field *f = (*fields)[j];
                 printf("field %s is of type %s\n", f->getName(),
                        f->getType()->getName());
 } }  }
```

Code Coverage Testing Using Dyninst

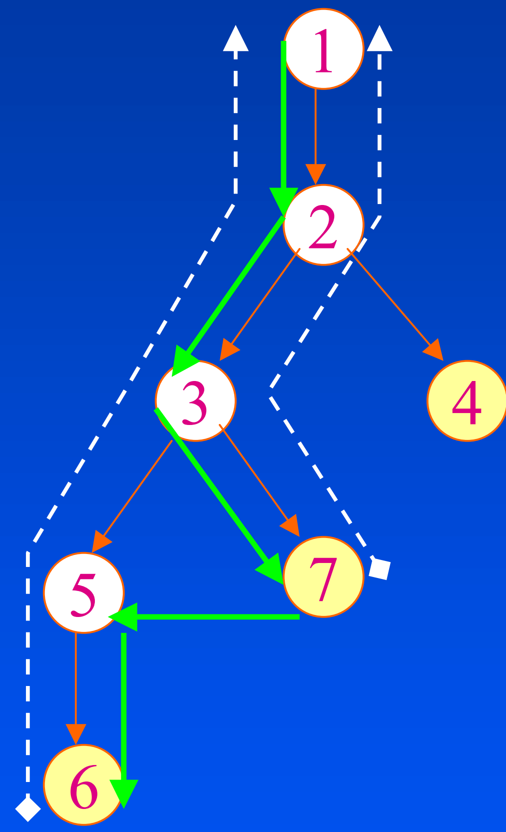
- Code Coverage
  - identifies source code lines not executed
  - ensures each basic block is taken at least once
- Using Dyninst
  - Allows use on arbitrary binaries
  - Permits removing code once a block is covered
    - Long running programs can be tested faster
  - Permits incremental instrumentation
    - First instrument function entry
    - On first call, instrument function's blocks

Using Dominators to Reduce Counters

CFG

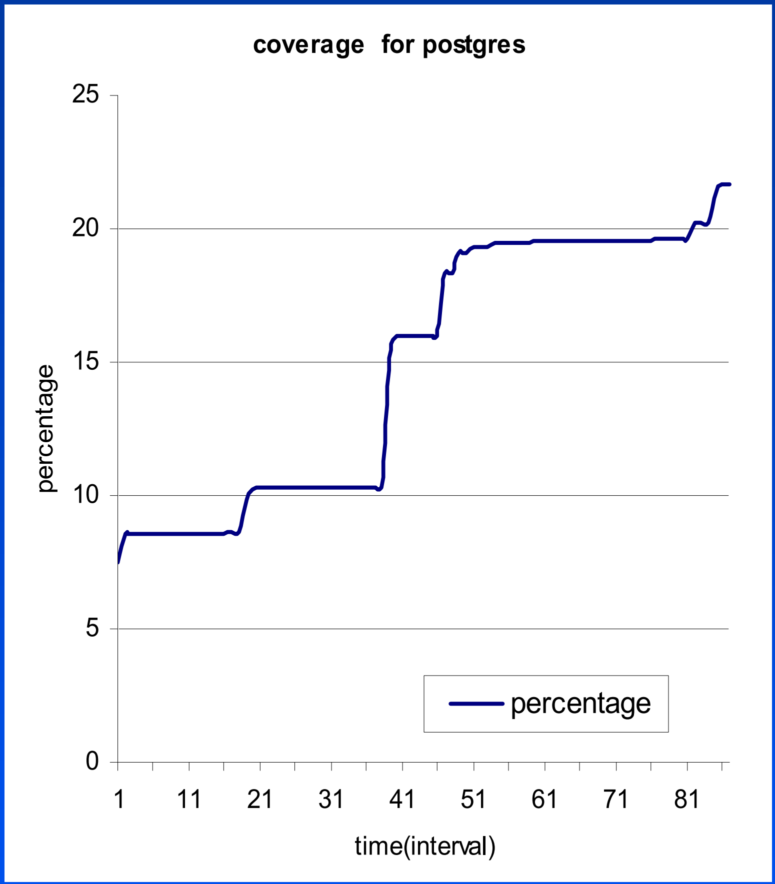


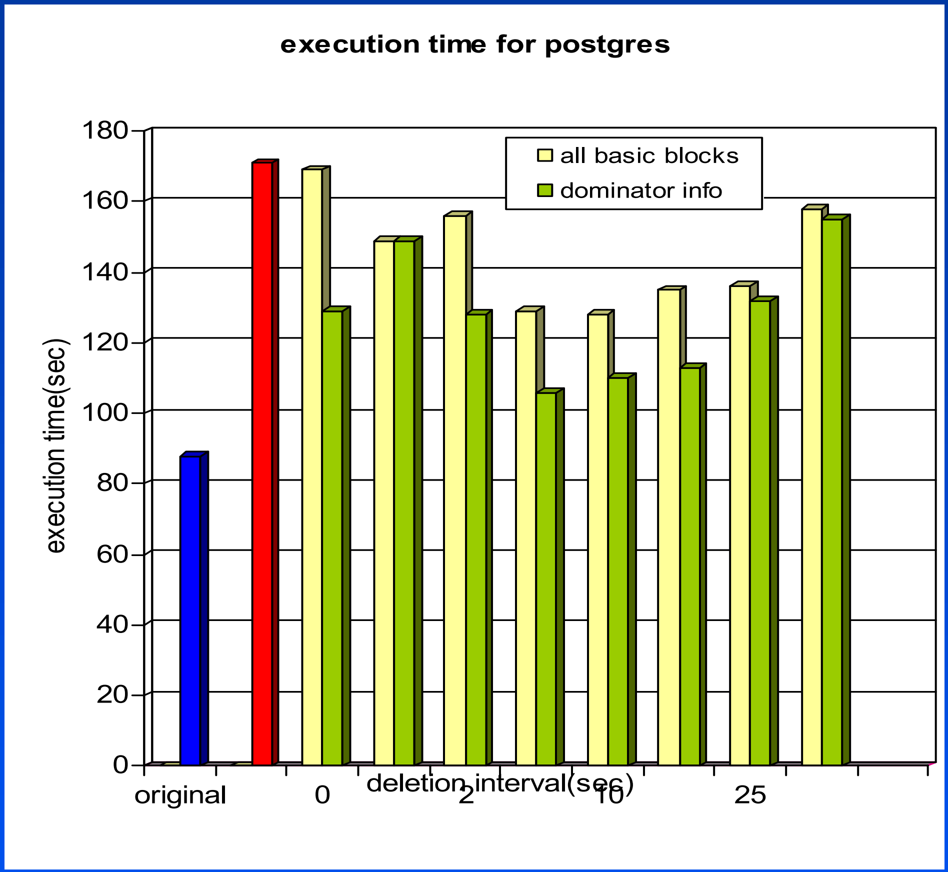
Dominator Tree



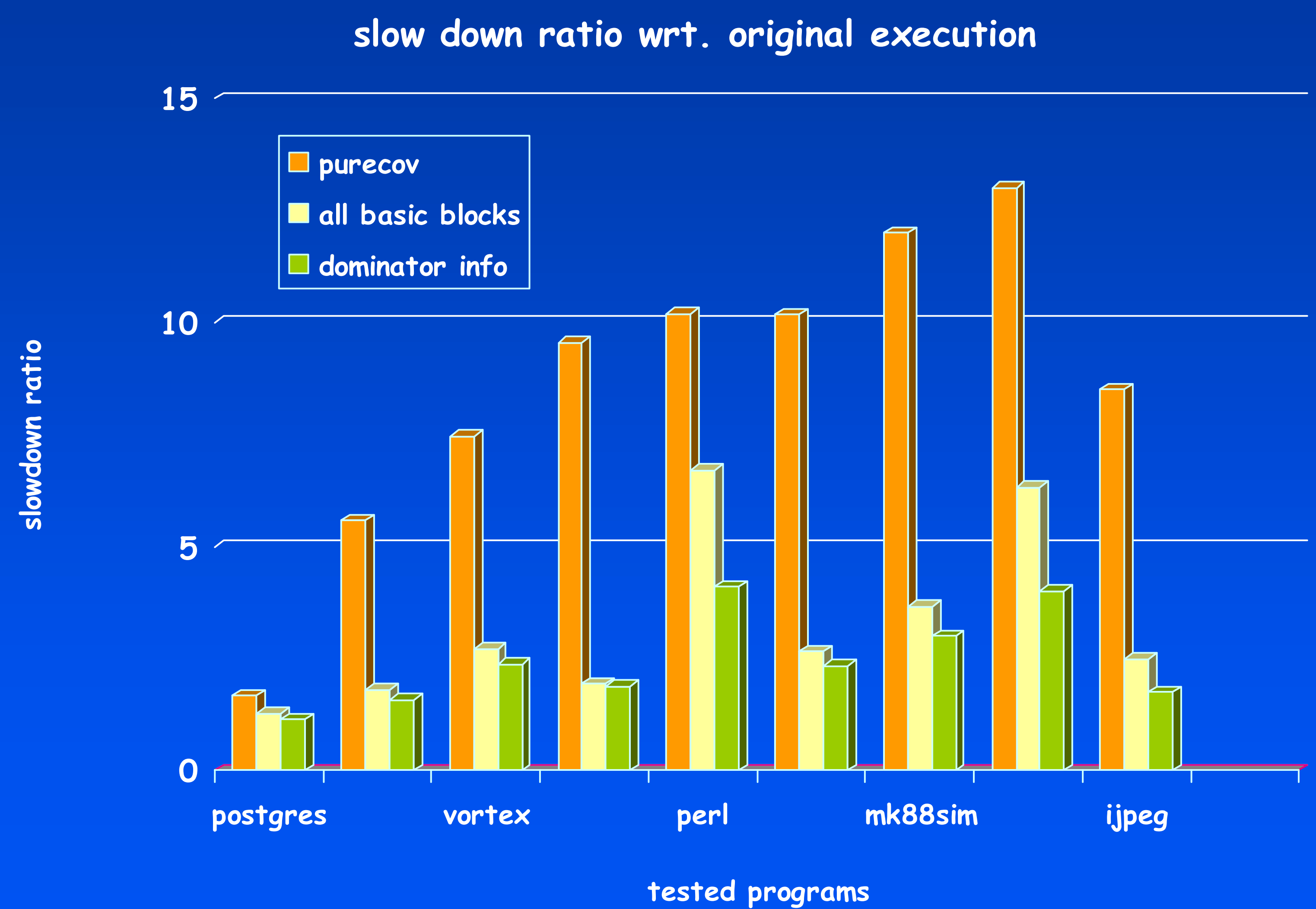
- instrument basic blocks that are leaf nodes in dominator tree
- Also instrument basic blocks with outgoing edge(s) to blocks not dominated by them

Postgres with Wisconsin benchmark





Slow down


slow down ratio wrt. original execution
15
10
5
0
purecov
all basic blocks
dominator info
slowdown ratio
postgres
vortex
perl
mk88sim
ijpeg
tested programs

Dyner Command Utility

- TCL-based command line tool
  - provides access to most dyninst features
  - easier to program for simple applications
  - can be used as a simple command-line debugger
    - fast conditional breakpoints
    - dynamic addition of printfs
- Command Summary
  - declare: create a new variable in the application
  - cbreak: insert conditional breakpoint
  - print: show contents of application data structures
  - at: insert a code snippet into the application
  - load, run, exit: process creation and manipulation

TCL Command Example

```
% load application
% declare int counter
% at main entry { counter = 0; }
% at importantFunc entry { counter++; }
% at main exit {
        printf("function called %d times\n",
                counter);
  }
% run
```

Dyninst Status

- Supported platforms
  - SPARC (Solaris)
  - x86 (Solaris, Linux, NT)
  - Alpha (Tru64 UNIX)
  - MIPS (IRIX)
  - Power/PowerPC (AIX)
- Software available on the web
  - http://www.cs.umd.edu/projects/dyninstAPI
  - Includes TCL command tool (soon)

Expanding the Application/System Interface

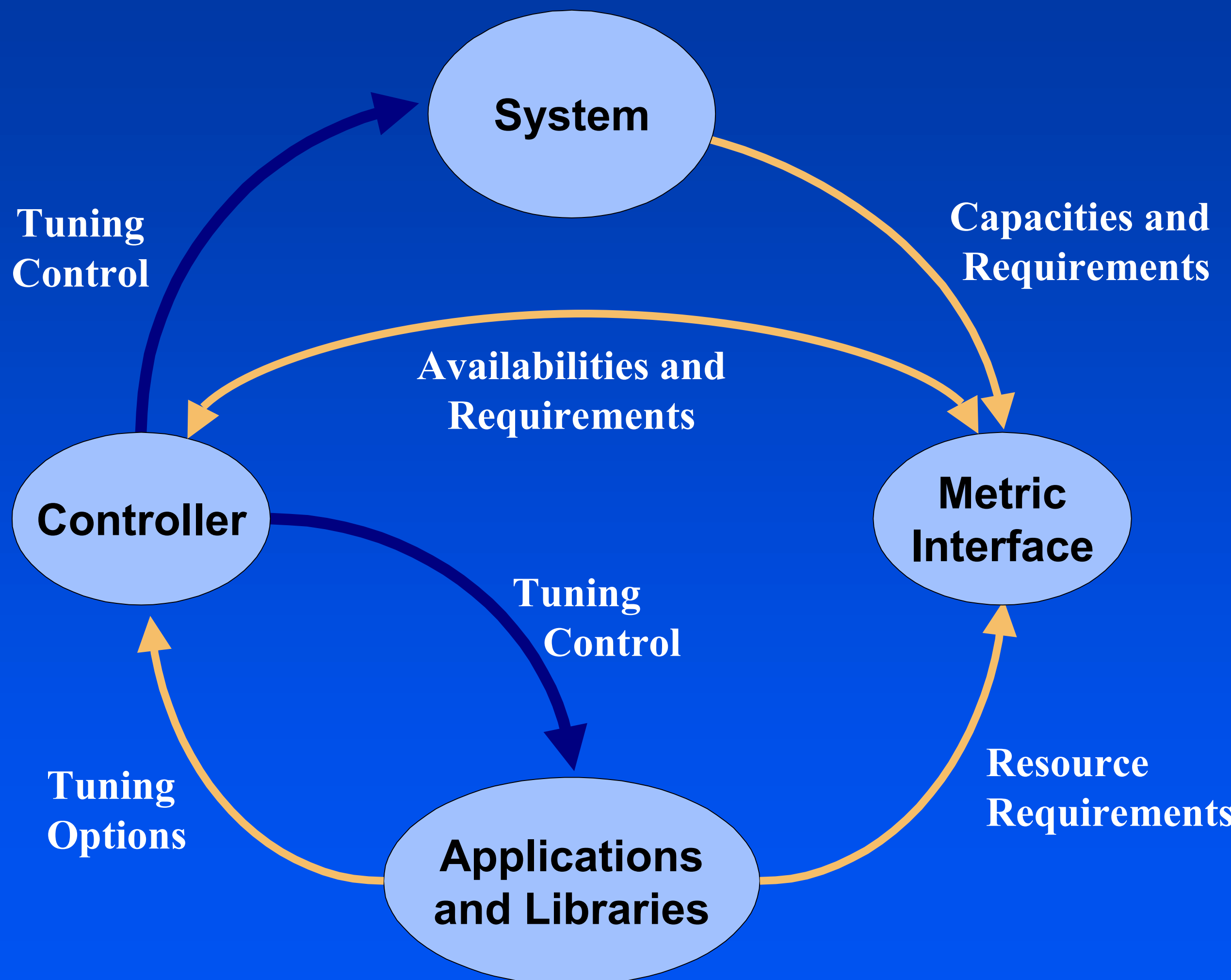
Past Model:

- Start program execution, hope for best

New Model:

- Application exposes alternatives
  - different algorithms/parameters
  - performance expectations for options
- System adapts application to optimize execution

Harmony Structure



Features of Harmony RSL

- Bundles
  - primary unit of adaptation
  - mutually exclusive sets of application options
- Resource Requirements
  - expected utilization for each option and resource
- Performance Prediction
  - expected performance of selected bundles
  - allows optimizing multiple applications on a system

Bundles

- *node*
  - CPU speed/disk capacity/available memory
- *link*
  - latency/bandwidth/protocol between nodes
- *communication*
  - entire application's communication requirements
- *performance*
  - entire application's performance
- *granularity*
  - switching between options at runtime

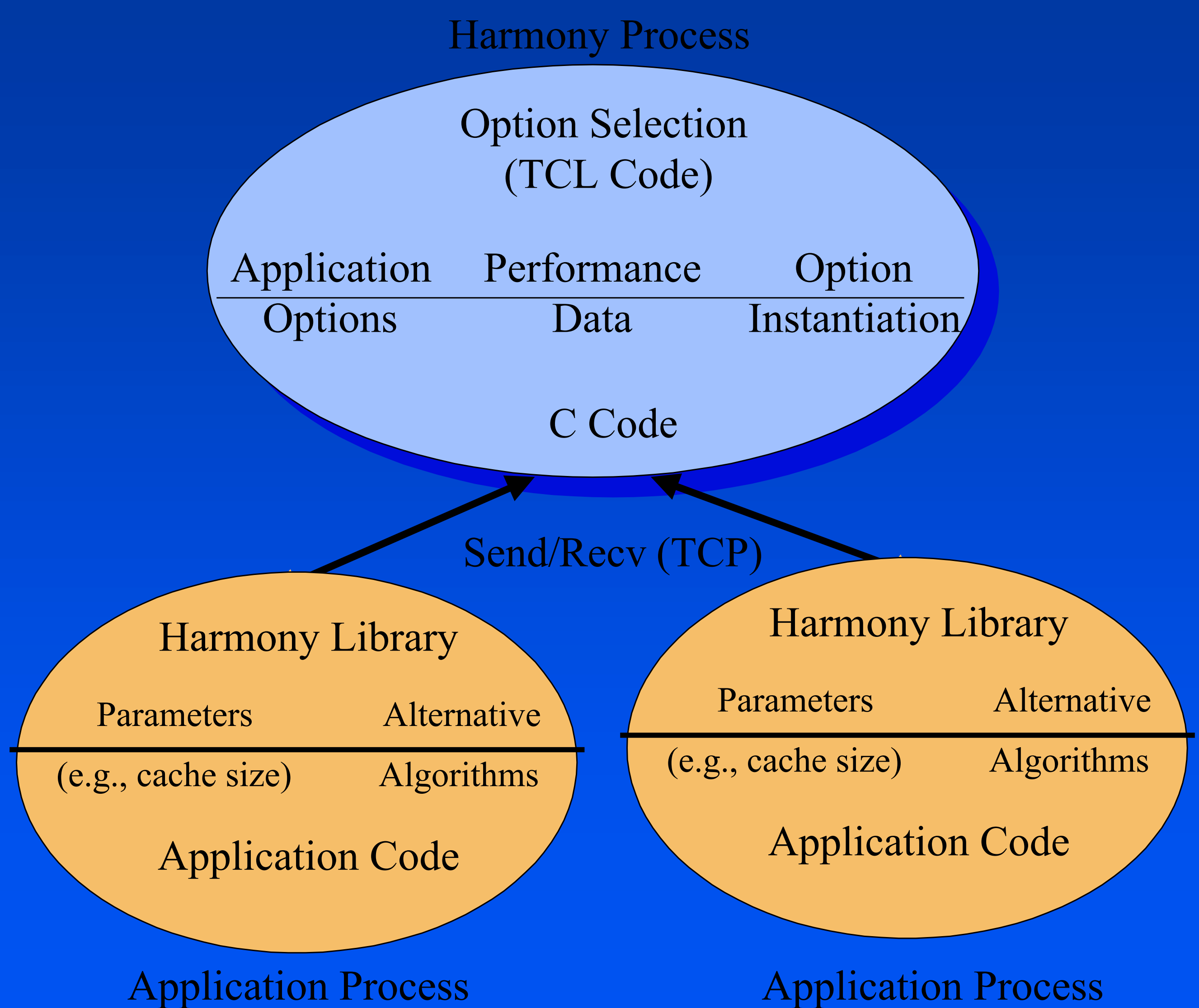
Harmony API

```
harmony_startup(<unique id>, <use interrrupts>)

harmony_bundle_setup("<bundle definition>")

void *harmony_add_variable("name", <default>, <type>, <func>)

harmony_wait_for_update()

harmony_end()
```

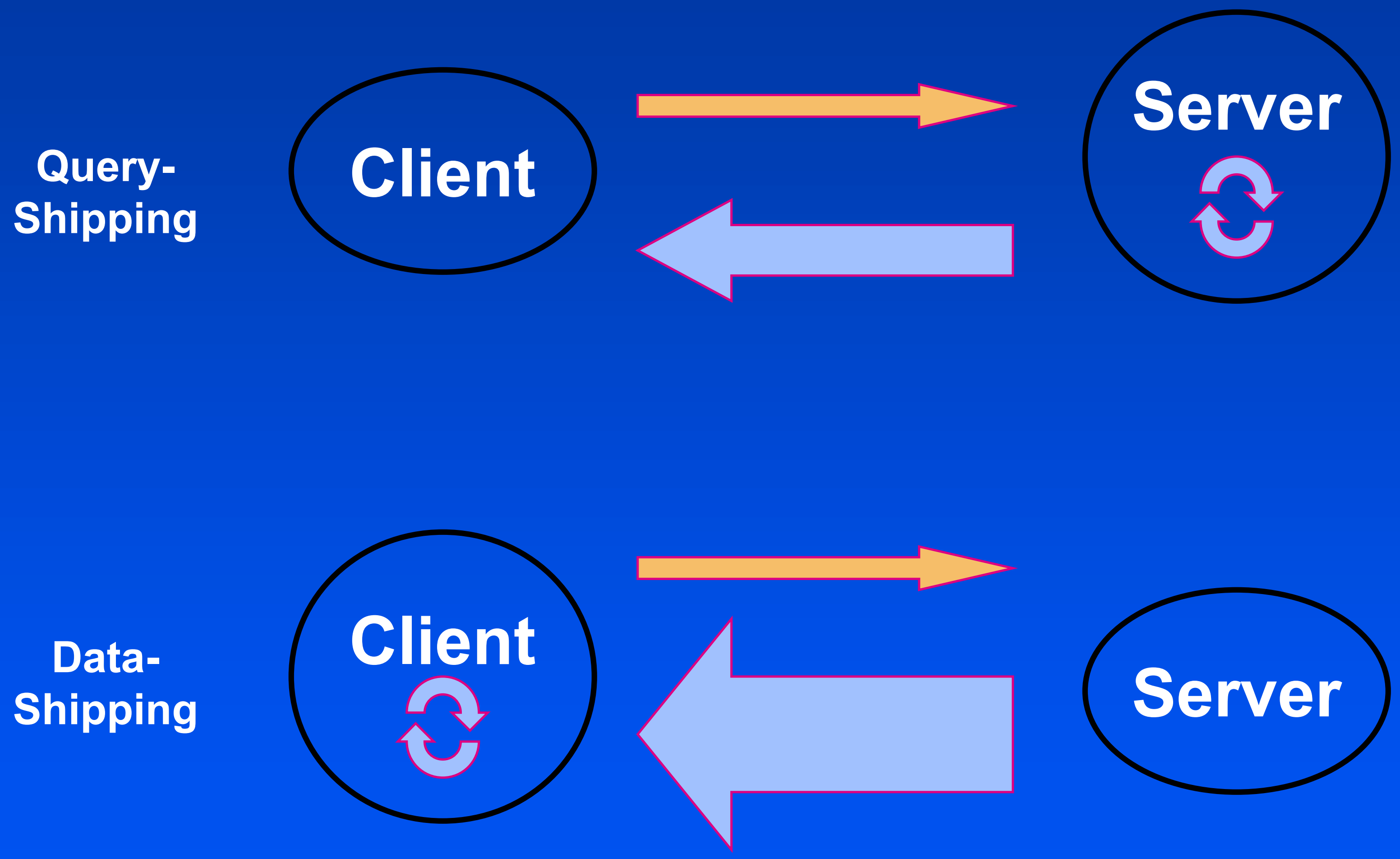
Used by application to:

- define options
- learn of harmony selections
- receive information about the environment

Architecture of Harmony Implementation



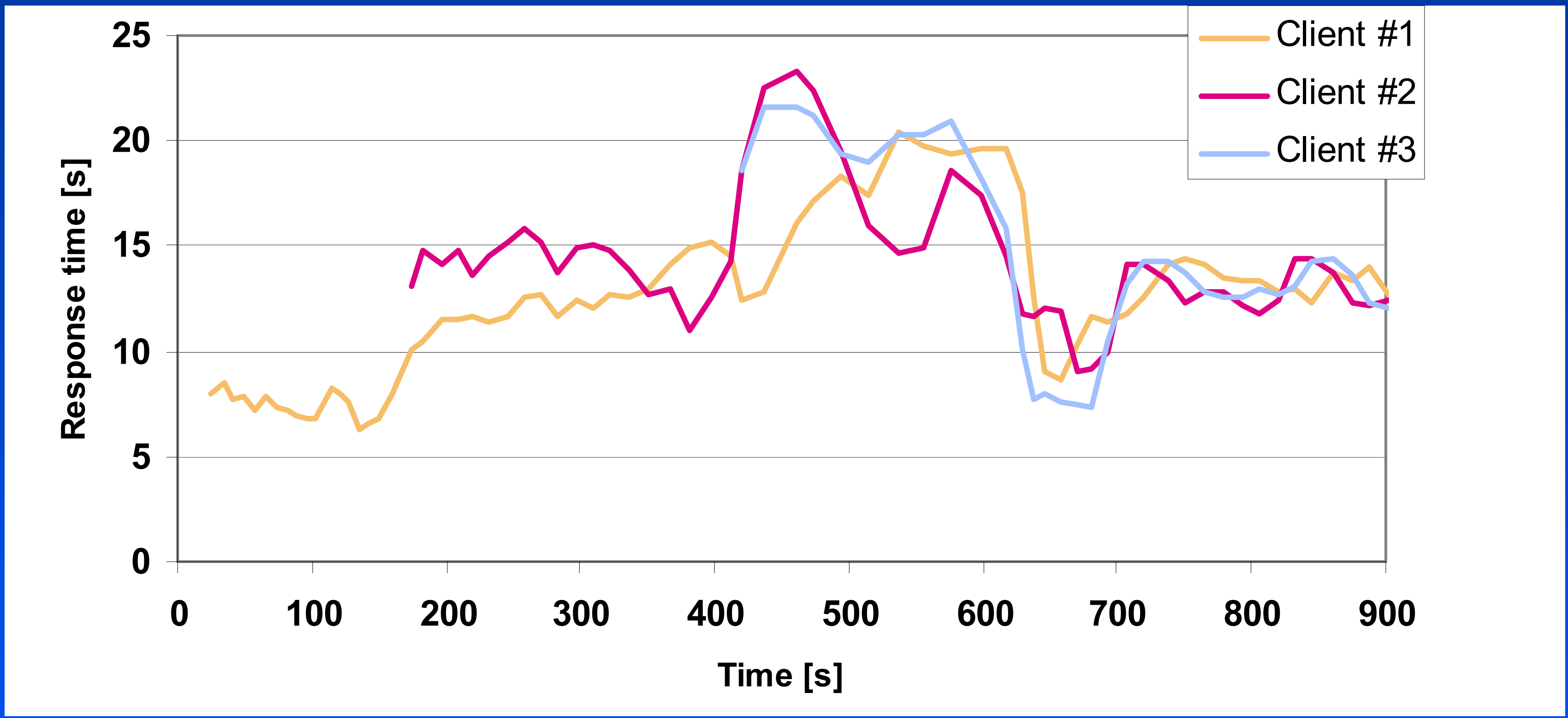
Example: Client-Server Database



Database Bundle

```
harmonyBundle Dbclient:1 where {
   {QS   {node     server
                   {seconds          9}
                   {memory           20}}
         {node     client
                   {seconds          1}
                   {memory           42}}
         {link client server 2}
   }

   {DS   {node     server
                   {seconds          1}
                   {memory           20}}
         {node     client
                   {memory           >=17}
                   {seconds          9}}
         {link client server {44 + (client.memory > 24 ? 24 :
                             client.memory) - 17}}
   }
}
```

Client Response Times



Clients added one at a time:

- First two clients run with query-shipping
- Third client flips all to data-shipping

Results from PSTSWM

- Solves nonlinear shallow water equations
- Contains many options:
  - Multiple algorithms embedded in the code
  - Problem-specific options
  - Communication Parameters

		All Combinations		Best Combinations	
Size	Nodes	Min	Max	Min	Max
T42L16	4	0.75	1.52	0.75	1.49
T42L16	8	0.50	1.03	0.50	0.77
T85L32	4	9.55	20.89	9.55	15.38
T85L32	8	5.99	11.41	5.99	7.90

Current Work

- Application resource usage
  - *potential*, not necessarily achievable
  - user, compiler, profiling
- Performance prediction
  - structural models
  - *POEMS*, AppLeS
- Scheduling!
  - Heuristics
- More applications
  - real-time vision, web server, video server

Active Harmony Conclusions

- Launch and forget is not sufficient:
  - Capacities are dynamic
  - Demands are dynamic
- System-directed adaptation gives us:
  - Complete information
  - Handles to running applications
- But requires:
  - Application restructuring (or layering, i.e. DSM)
  - Detailed resource requirements

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