Wiggins/Redstone: An On-line Program Specializer

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W/R is a Software System That:

- Makes arbitrary binary applications run faster without requiring any work from the programmer
- Aggressively optimizes/specialize an application for a particular use on a particular machine
- Moves optimization/compilation closer to the actual use of the program

W/R is On-line

- Executes dynamically while the program is running
- Uses path profiles
- Modifies in-memory images to take advantage of:
  - Data values
  - Temporal effects

Motivation

- Static code optimization (at compile time)
  - Know little about the dynamic behavior of programs
  - Know little about the actual machine
  - Know nothing about the actual data
- Feedback directed optimization gets some knowledge of dynamic behavior, but is tricky to use
- Prior dynamic approaches not general purpose

W/R

- Binary images
- Paths
- Specializes code in many ways
- Opts are platform dependent
- Starts with the code produced by an optimizing compiler

Hotspot

- Java
- Procedures (or parts)
- Specializes code to remove virtual calls
- Opts are platform independent
- Starts with the code produced by a JIT

W/R Approach

- Input is an arbitrary binary without any special compilation switches or annotations
- Load the profiler and optimizer into the application
- Do the specialization at run-time
- Use value profiling at key points
- Optimizations performed are specific to the underlying micro-architecture
- Optimizations are also data set specific

W/R Benefits

- At run time, automatically (without programmer direction) reorganize, optimize and specialize important dynamic code sequences
- Exact knowledge of:
  - Program behavior, phases
  - Program invariants (glacial variables), data
- Low overhead

Relationship With Hardware

- Hardware engines are starting to optimize code
  - Out of order execution
  - Branch and value prediction
  - Trace processors
- W/R uses hardware (performance counters) to direct the software to start building software instruction traces
- Dynamic compilation may be required to exploit new hardware
- Not either/or software/hardware technique

The W/R System Architecture

1. The agent - A modified loader/launcher that starts the system
2. A low overhead, hardware based sampler
3. A trace builder that finds and instruments parts of a program
4. Optimizer/specializer (works on superblocks)
5. OS independent
   - Windows NT
   - Tru64 UNIX

System Flow

While the program is running {

1. Identify a hot instruction
2. Build a trace containing the instruction
3. Instrument the trace
4. Specialize the trace
5. Optimize the trace

}

Step 1 is hardware, 2-5 are software

Agent

- A special loader
- Adds code to an image when started. This code contains the profiler and optimizer
- The agent is shared over applications
- The agent knows about the actual platform, so old programs can run on new platforms
- Allows us to add new optimizations to old programs

Sampler

- We use a hardware PC sampler to find “hot” seed instructions
  - The sampler is a source of frequent interrupts
  - Look for frequent values of program counter at
  - Interrupt time
  - Code is based on DCPI
- Approach works on out-of-order machines such as 21264

Trace Builder

- Given a seed instruction
  - Copy it and the remainder of the block to a side buffer
  - Add instrumentation code, guards to insure correctness, branch back
  - Patch the image to branch to the copy
  - After the instrumentation code finds the most common successor extend the copy
- Copied instructions form a superblock
- Effectively a lazy instruction trace constructor

Optimizer/specializer

- Specializes "hot" traces using machine-specific information. Introduce guards as necessary
- Exploits temporal info
- Analyzes what to monitor
- Performs architectural and micro-architectural optimizations (byte/word loads and stores on alpha)
- Applications will continuously monitor themselves and perform self-improvements whenever necessary

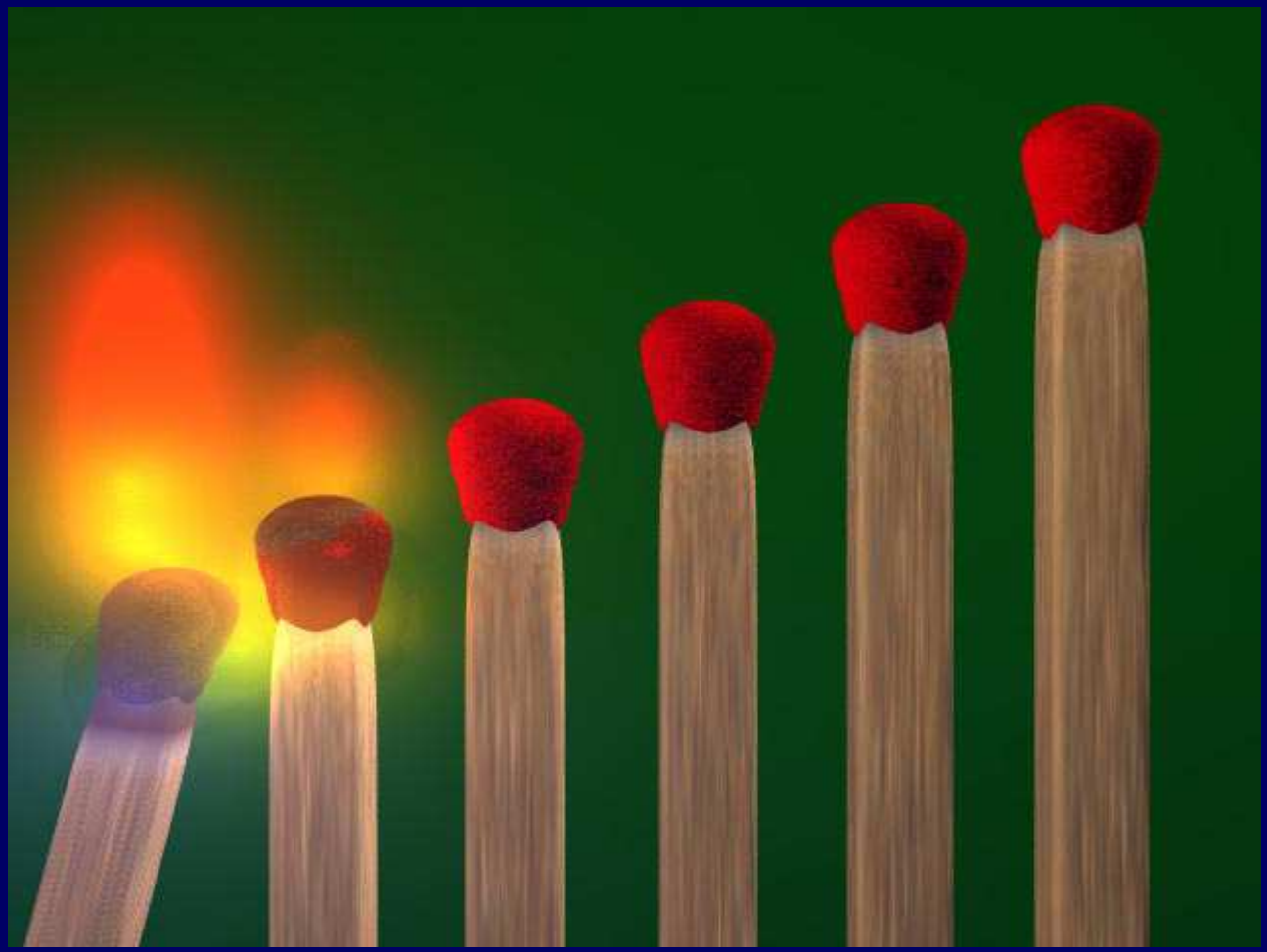
Advantages

- The application carries no machine-specific information
- Can update the agent to incorporate new optimization techniques as they become available
- Programs compiled using generic or 21064 specific features run faster on 21164; 21164 specific programs run faster on 21264, ...

Some Data Points

- Povray - a freely available rendering package
- Image “matches.Pov”
  - 2 billion calls to power(x,y)
  - If you perform three levels of inline on the frequent path you find that y = 8.0
  - Calls to power() are on the frequent path 95% of the time

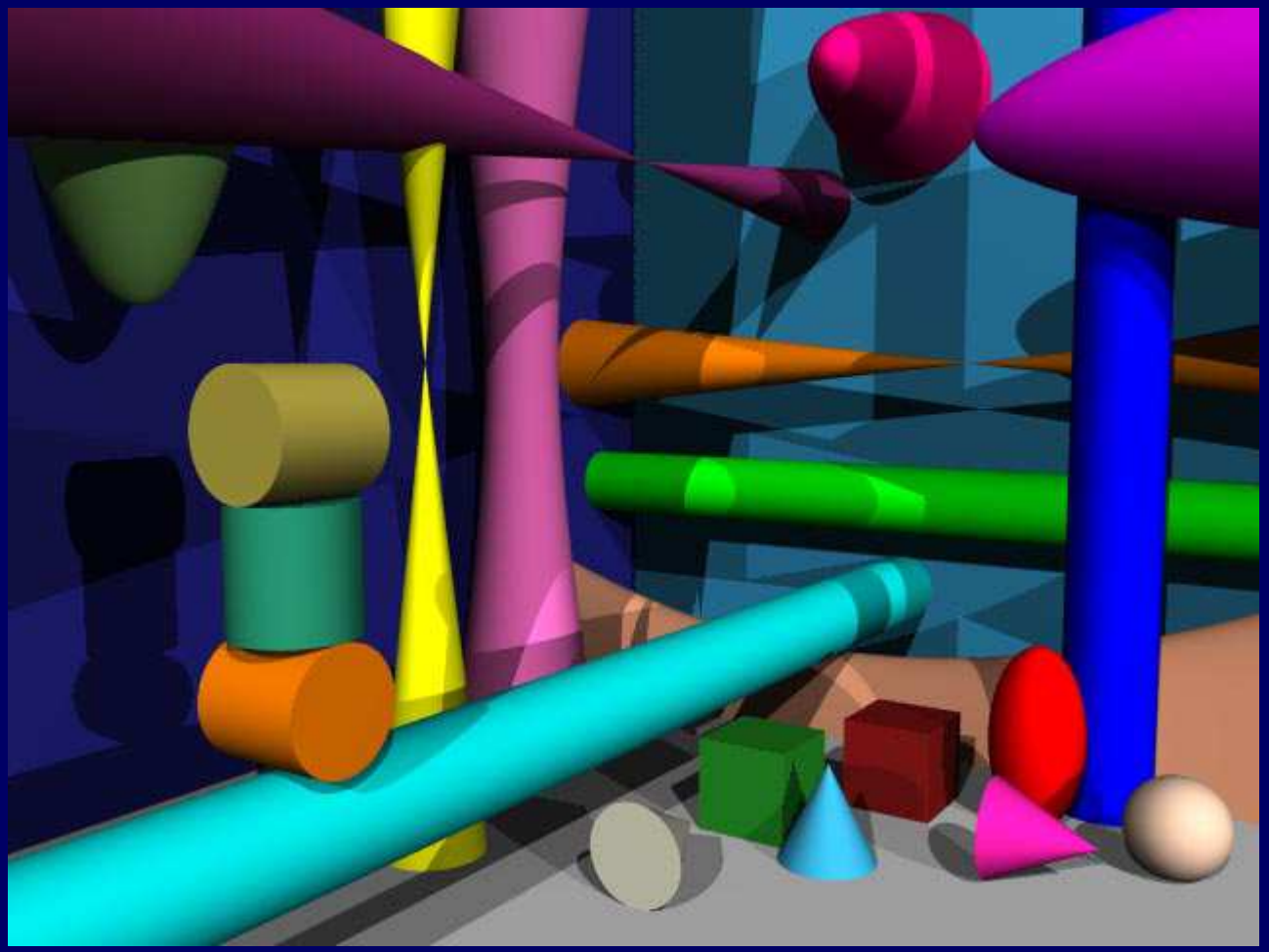
Povray Image



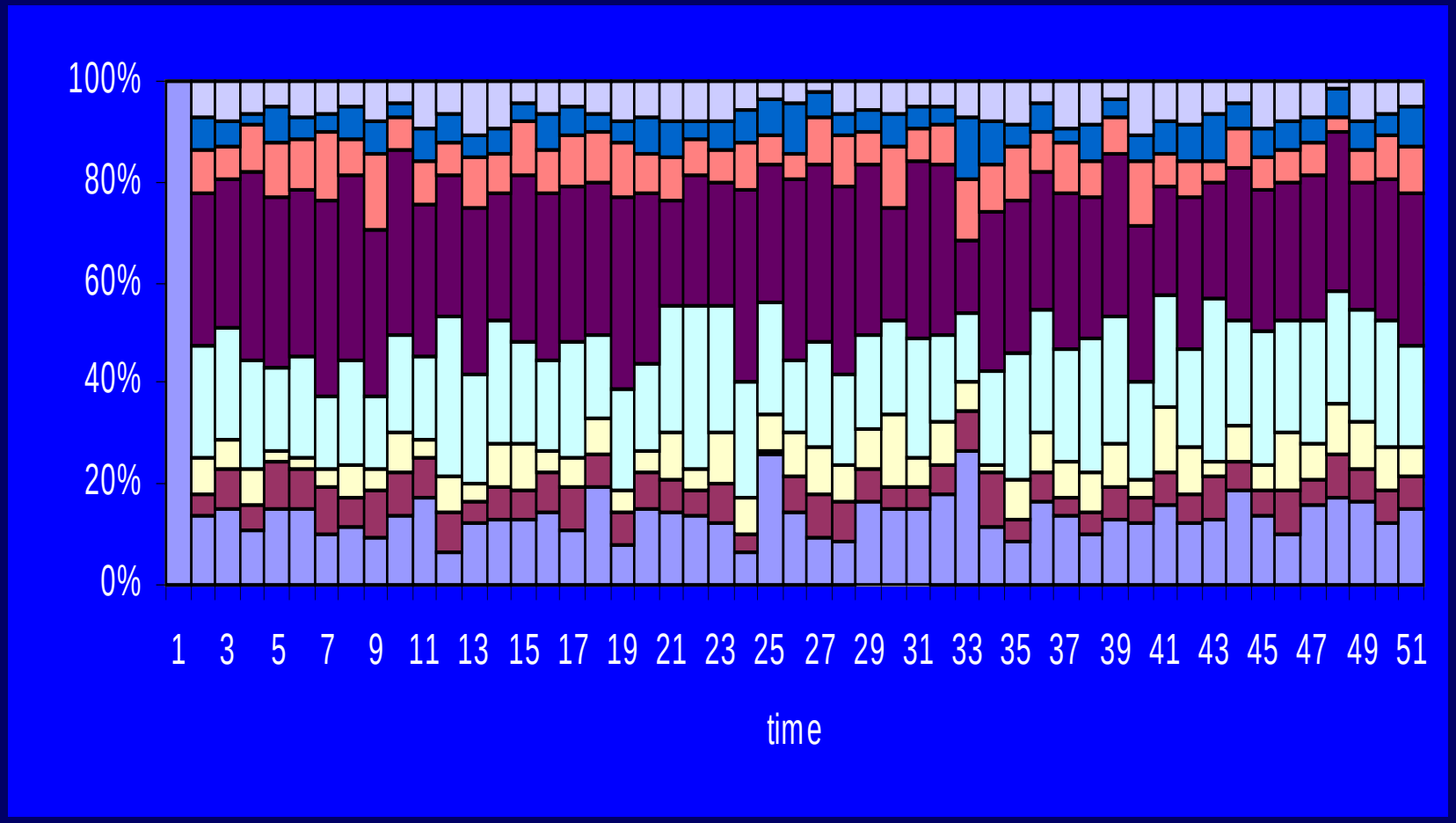
How Many Traces?

- Typically less than16 traces at a time
- Traces contain several hundred instructions
- Traces often account for 50-90 of the run time of an image
- Traces are removed as the computation evolves

PovRay shapes.pov Demo



Percent of Time on Traces



Characteristics of Traces
(shapes.pov)

- Povray: 661069 static instructions
- Traces
  - 7 traces total
  - 1586 instructions (0.239%)
  - 819 unique instructions (0.123%)

Characteristics of Traces

- Inter-procedural
  - Often 2-4 levels deep
- Can include one loop
  - But may include many unrolled loops
- May be up to 2000 instructions long
  - Often 300-500 instructions
  - Long enough to insert pre-fetch instructions
- Need not stop at a register transfer, return, or call site

Conditional Branches (Cbrs)

- 76 unique cbrs
- 115 instances of a CBR show up on various traces
- Trace probabilities vs. Aggregate probabilities
  - Correlated branches
  - Temporal effects
- 5-10% of branches have multiple instances with reversed directions

Cbrs Vs Static Branch Probs

Branch	Trace	Probability	Aggregate
0x12003cc48	3	1.00	0.13
	8	0.00	
0x12003cc74	3	0.00	0.00
0x12003cc9c	1	1.00	1.00
	3	1.00	
	3	1.00	

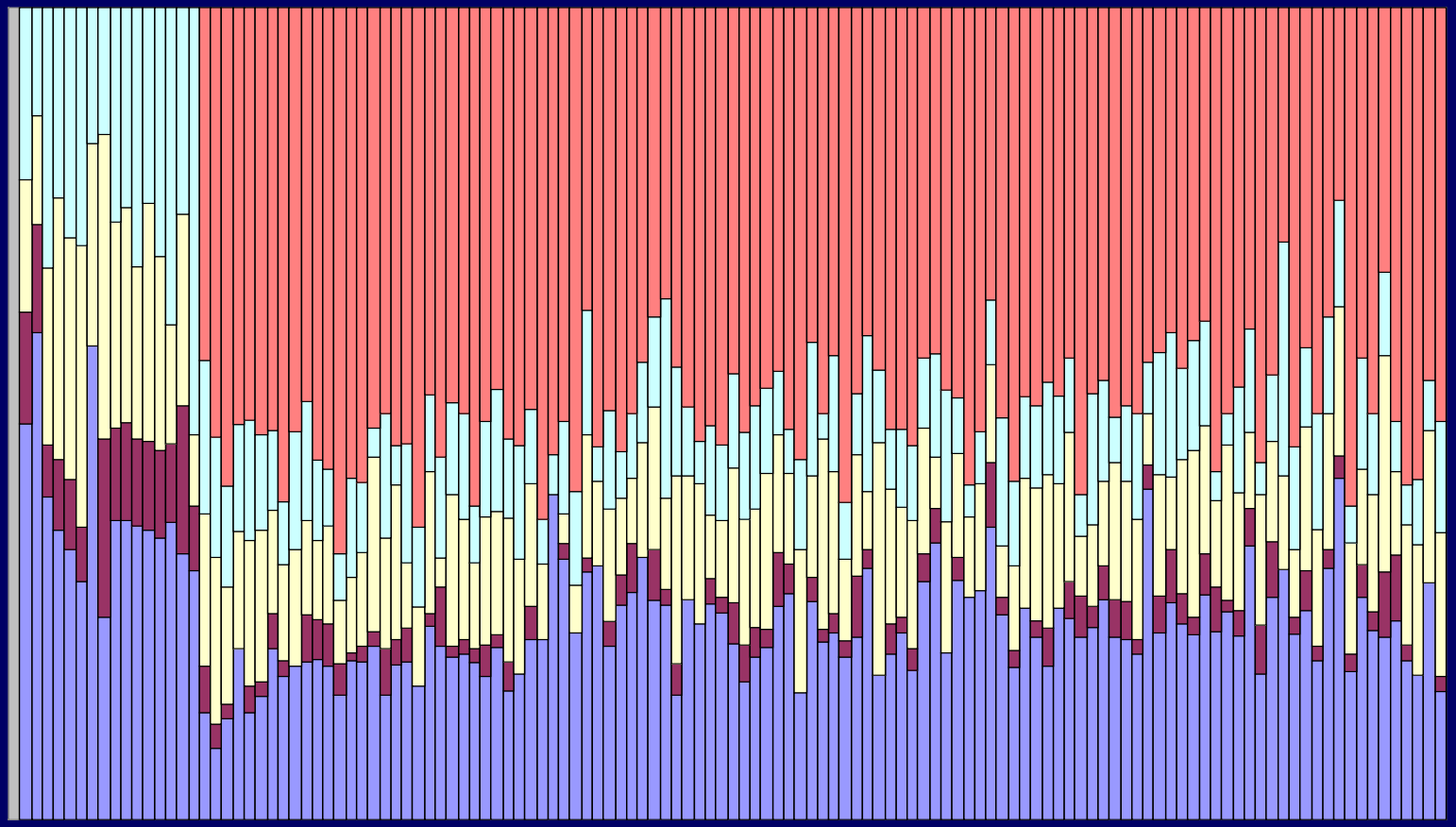
Temporal Effects

- A single program using one data set can show phases, which may not be apparent in the source code
- Different phases require different optimizations
- E.G.. Compress (SPEC95) -
  - For each data item - look it up in hash table
  - Initially most items are not in table
  - Later most items are in table

Sunsethf.pov

Trace construction (Time)

Temporal Effects



What Don't We Do?

- W/R works on applications not system kernels
- Does not modify OS components
- Does not modify program memory layout
- Does not work with device drivers

Final Comments

- Wiggins/Redstone is the software analog of a trace processor
- Runs on stock hardware/stock OS
- Optimizes/specializes binary images
- Runs on-line
- Captures temporal effects
- One tool, in a more adaptive computing model?
- Return to self-modifying code?