Center for Scalable Application Development Software (CScADS):

Automatic Performance Tuning Workshop

http://cscads.rice.edu/

Katherine Yelick

LBNL and UC Berkeley

CScADS Goals

- Conduct research leading to software tools and systems to help applications scale to the petascale and beyond
  - Focus on DOE systems at ORNL, ANL and NERSC
  - Focus on systems composed of multicore processors
- Catalyze activities in the computer science community
  - Focus on interactions with systems vendors, application developers, and library designers
  - Includes a series of workshops
- Foster development of new software through support of common software infrastructures and standards
  - E.g., Open64, ROSE (with LLNL), Telescoping Languages, D System, Dyninst, HPCToolkit

CScADS Participants

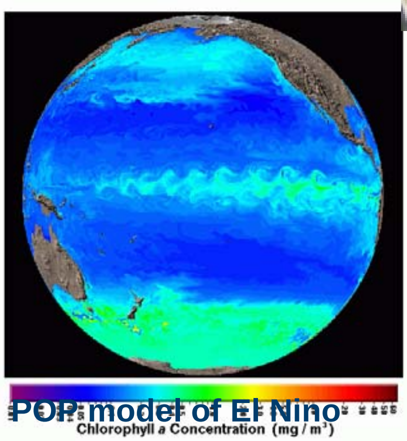
- Funded by DOE SciDAC program
- Rice University (Lead Institution)
  - John Mellor-Crummey (Lead PI), and Keith Cooper
- Argonne National Laboratory
  - Peter Beckman (Site Director), William Gropp, and Ewing Lusk
- University of California, Berkeley
  - Katherine Yelick
- University of Tennessee, Knoxville
  - Jack Dongarra
- University of Wisconsin, Madison
  - Barton Miller

Performance Engineering Research Institute (PERI)

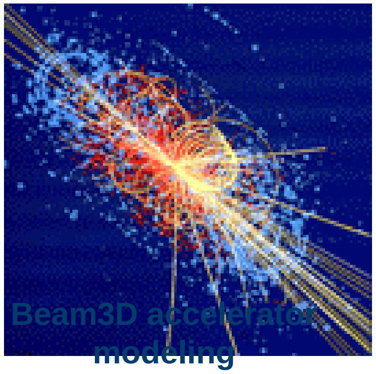
- Related SciDAC-funded project
- Goal: Performance engineering:
  - Systems are more complicated
  - Applications are more complicated
    - Multi-disciplinary and multi-scale
- PERI approach:
  - **Modeling:** performance prediction
  - **Application engagement:** assist in performance engineering
  - **Automatic performance tuning:** tools to improve performance

IBM BlueGene at LLNL

Cray Xt3 at ORNL



POP model of El Nino



Beam3D accelerator modeling

Participating Institutions

Lead PI: **Bob Lucas**

Institutions:

Argonne National Laboratory

Lawrence Berkeley National Laboratory

Lawrence Livermore National Laboratory

Oak Ridge National Laboratory

Rice University

University of California at San Diego

University of Maryland

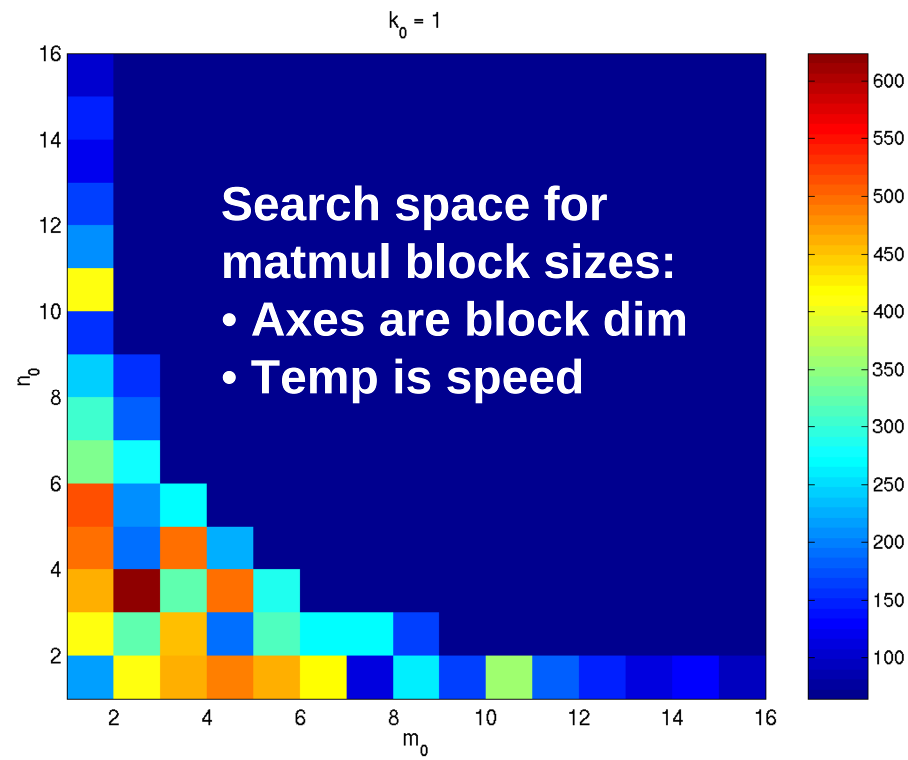
University of North Carolina

University of Southern California

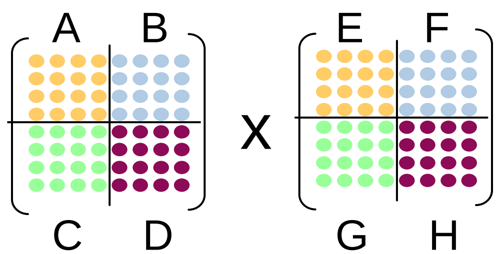
University of Tennessee

History of Autotuning: Need for Search

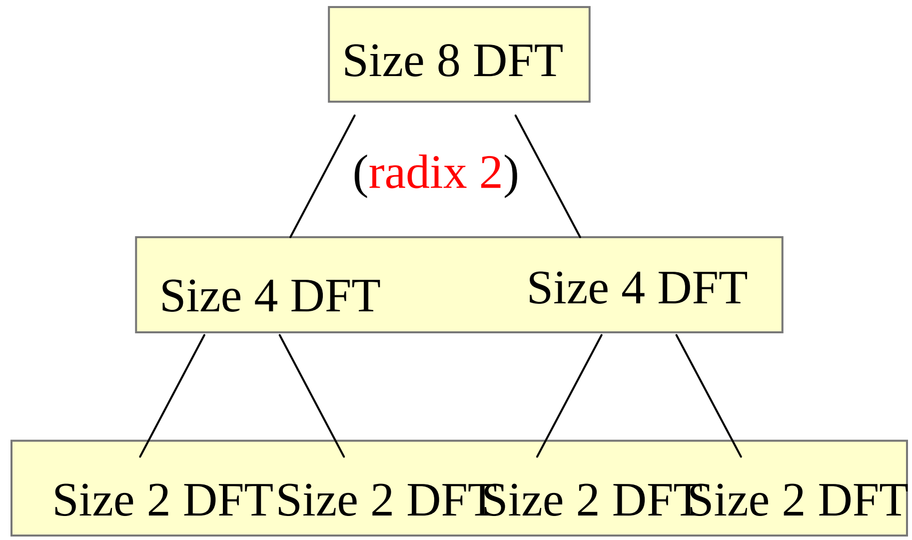
- Autotuning is the use of search to select from a set of possible code versions
- Automatic compared to the hand-tuning historically used for libraries (BLAS, FFTs, etc.)
- Example: tile size selection in dense matrix-matrix multiply
- Several papers on automated tiling (3 nested loops → 6 nested loops)
- Several papers on tile size selection, but not definitive



History of Autotuning: Use of Recursion



$$= \begin{bmatrix} A*E + B*G & A*F+B*H \\ C*E + D*G & C*F+D*H \end{bmatrix}$$



Recursion in Matrix Multiply

Recursion in FFTs

- Traditional implementations were non-recursive
- But the recursive formulation gives better locality

History of Autotuning: Portability through C

- Autotuning systems were made portable by using C as code generation language
- Many optimizations could be performed in C
  - Tiling, unrolling, software pipelining, data structure transformations, “register allocation” (explicit temps)
  - Although use of a C compiler adds a level of uncertainty into performance
    - Search over compiler flags and code versions
- C is used as the code generation language in FFTW, Atlas, OSKI, and in several research compilers
  - Inclusion of machine-specific pragmas, intrinsics, and even assembly code may also be permitted

How much coverage do autotuning systems have?

Phillip Colella's "Seven dwarfs"

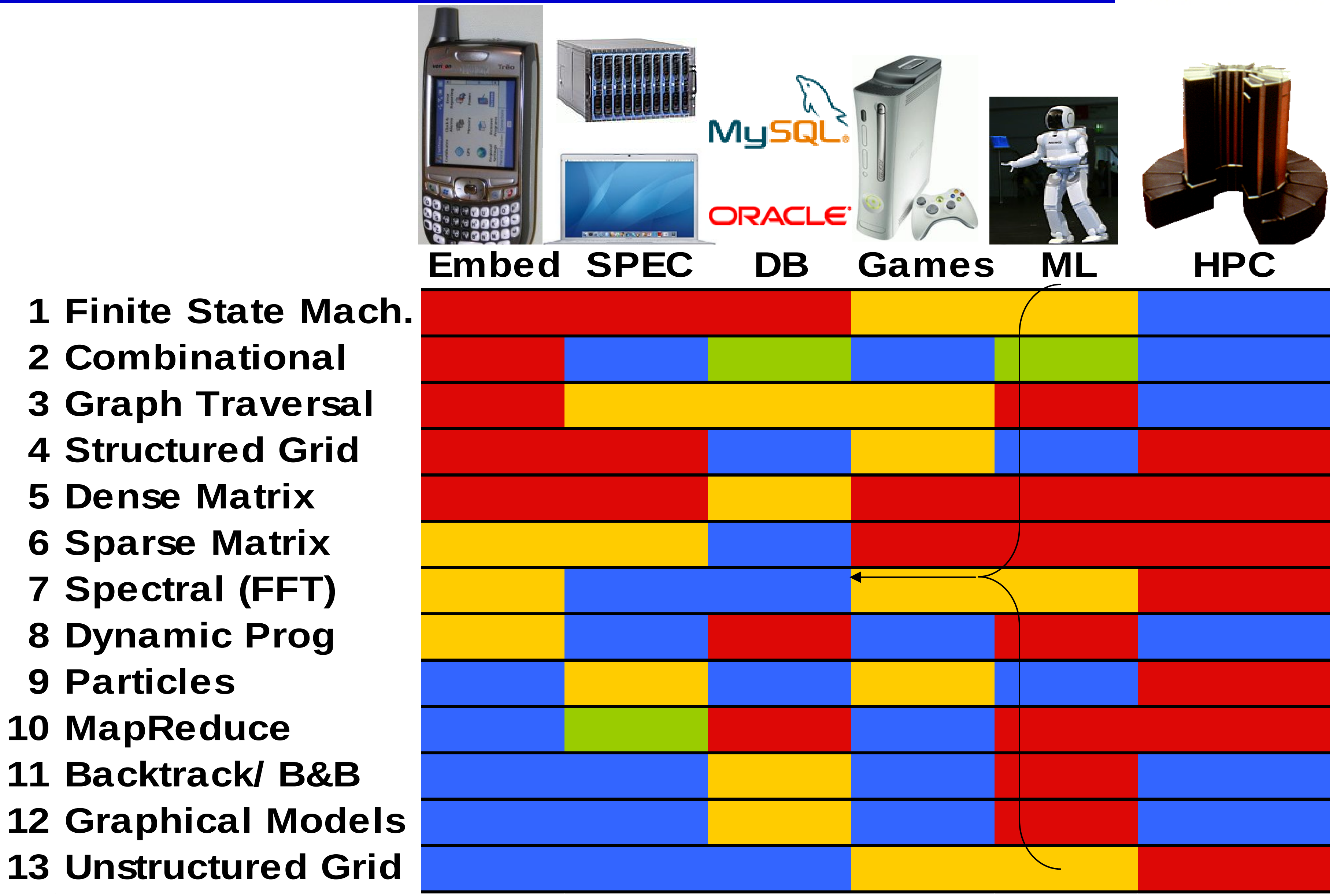
High-end simulation in the physical sciences = 7 numerical methods:

1. Structured Grids (including Adaptive Mesh Refinement)
2. Unstructured Grids
3. Spectral Methods (e.g., FFTs)
4. Dense Linear Algebra
5. Sparse Linear Algebra
6. Particles (including n^2, tree codes, and particle/mesh)
7. Monte Carlo

- defined A dwarf is a pattern of computation and communication
- Dwarfs are well-defined targets from algorithmic, software, and architecture standpoints

Slide from "Defining Software Requirements for Scientific Computing", Phillip Colella, 2004

Dwarf Use (Red Important → Blue Not)

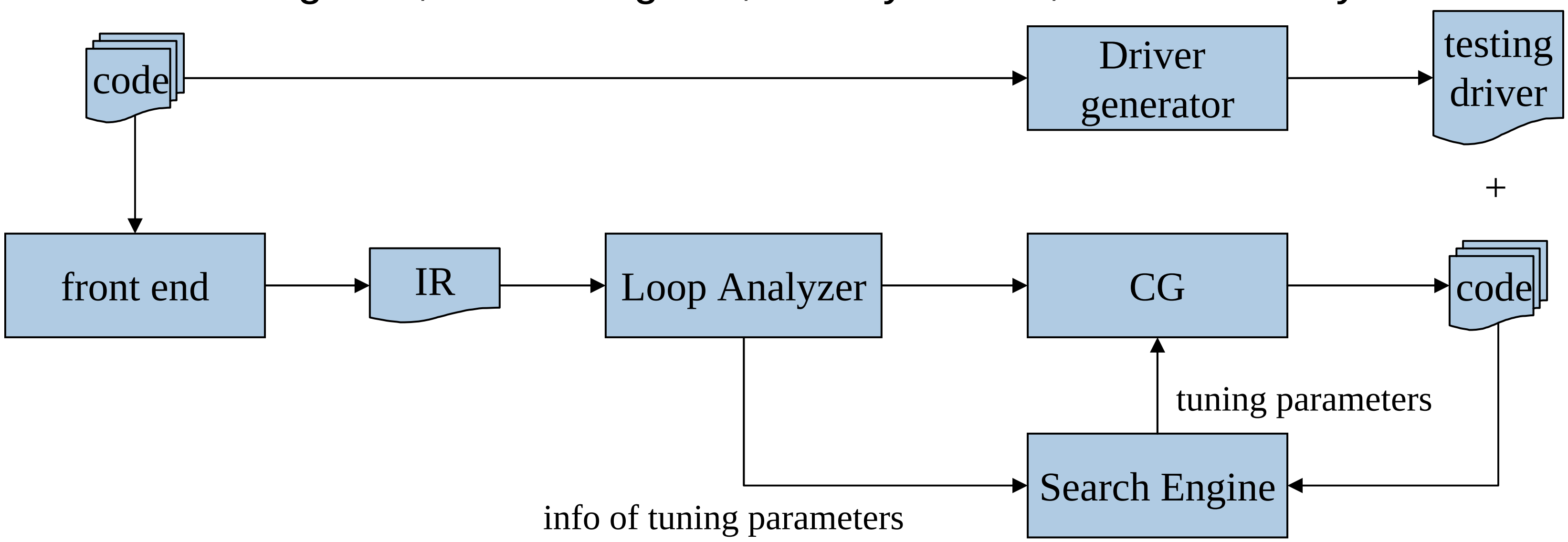


Autotuned Library Instances

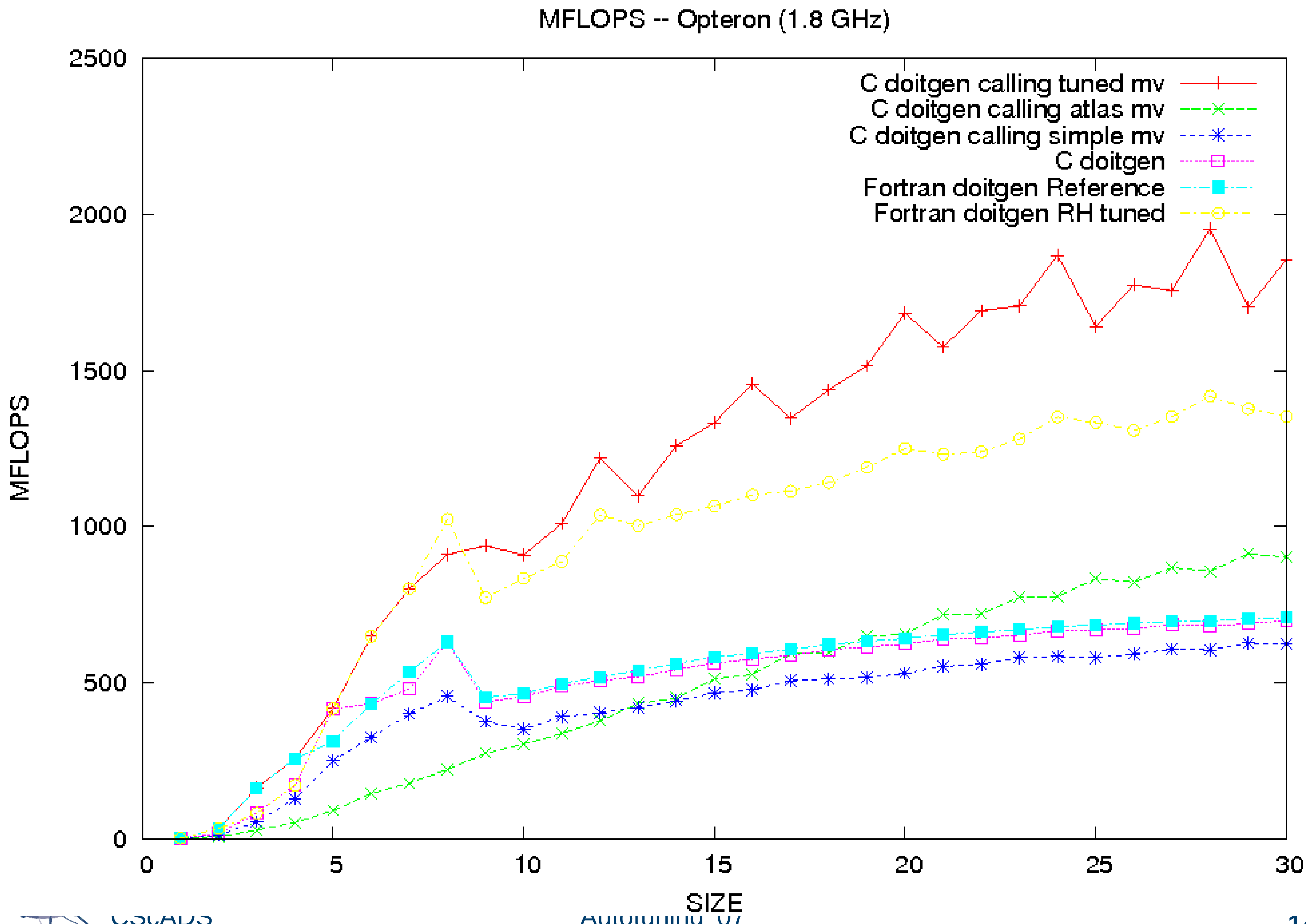
- Spectral algorithms: Spiral, FFTW, UHFFT,…
- Dense linear algebra: Atlas, PHiPAC
- Sparse linear algebra: OSKI, Sparsity
- Structured grids: In progress (Datta), Sketching (Bodik et al)

Compiler Level Autotuning Example

- GCO (Generic Code Optimizations) infrastructure
  - UT: Haihang You, Jack Dongarra, Shirley Moore, and Keith Seymour



- Application to Multiresolution Analysis Kernel from MADNESS using a Specialized Code Generator
  - Extract matrix-vector multiplication kernel from doitgen routine
  - Design specific code generator for small matrix-vector multiplication
  - Tune block size and unrolling factor separately for each input size


MFLOPS -- Opteron (1.8 GHz)
MFLOPS
SIZE
C doitgen calling tuned mv
C doitgen calling atlas mv
C doitgen calling simple mv
C doitgen
Fortran doitgen Reference
Fortran doitgen RH tuned
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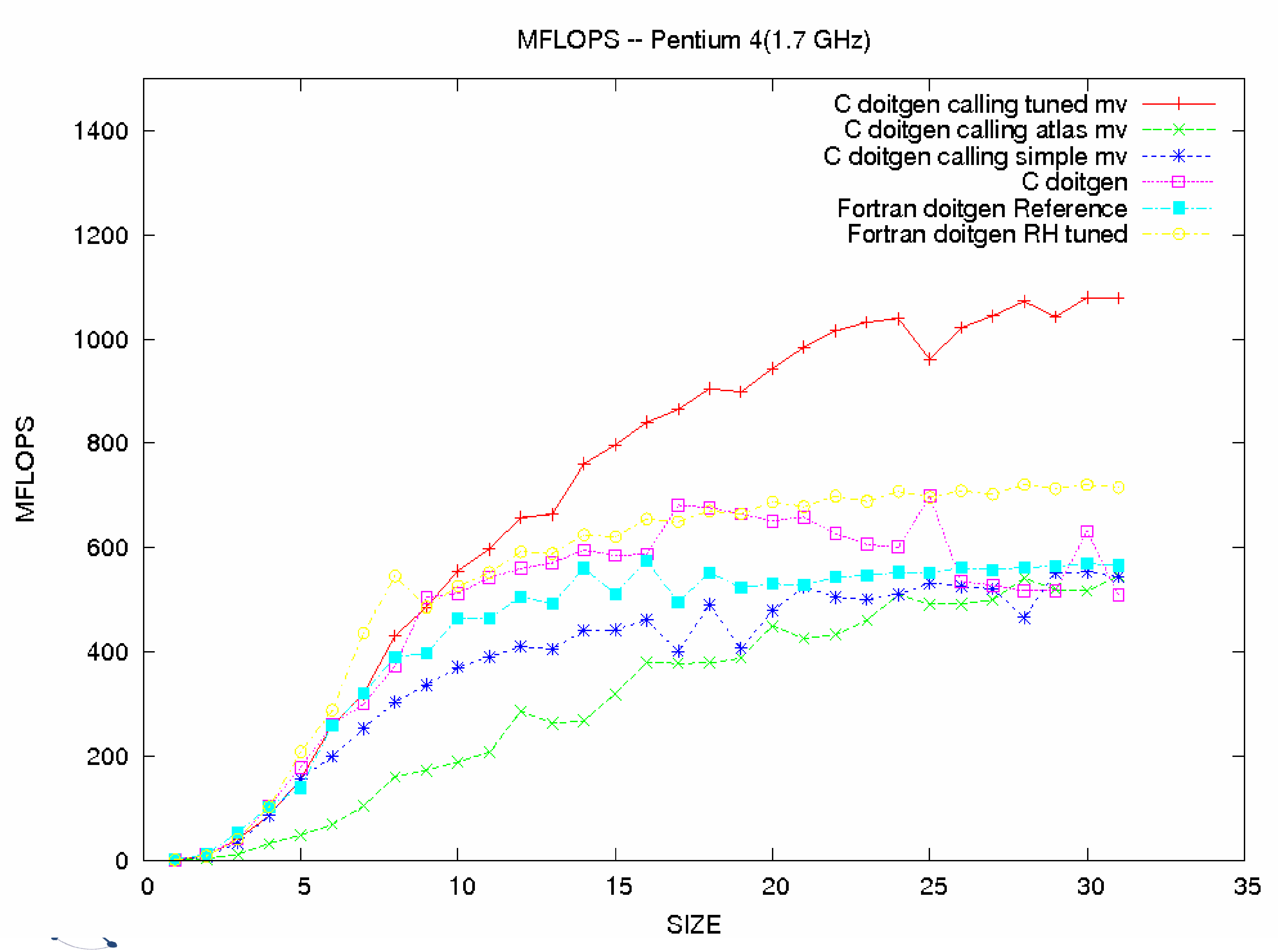
MFLOPS -- Pentium 4(1.7 GHz)
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Fortran doitgen RH tuned
MFLOPS
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35

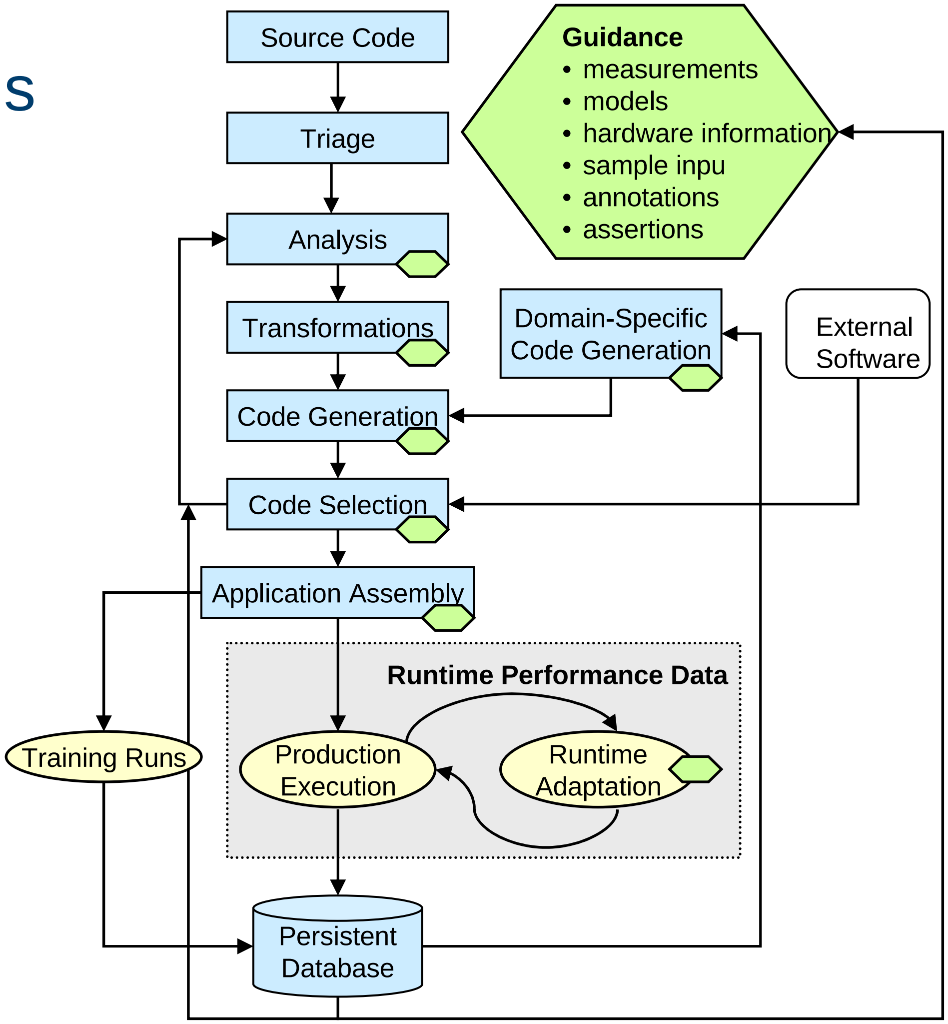
View of Automatic Performance Tuning in PERI

Automatic Tuning at many levels

- Libraries: generate code without analyzing or transforming source
- Compilers: source-to-souce transformations; whole application optimizations

Guidance controls tuning

- Performance models, measurements, annotations, assertions,…



PERI automatic tuning framework

Questions for Discussion

- Compilers: what they can/should do
- Cache oblivious vs. cache-aware
- Can autotuners help get us over the multicore hurdle?
- How much parallelism can autotuners handle? Does search space get too large?
- If cores get simpler, will autotuning be less important
- Performance models: are they predictive enough?

Agenda Days 1 and 2

Day 1 - Monday, July 9

- 8:00 Continental Breakfast

Overview and Libraries 1 (Spectral)

- 8:30 Kathy Yelick, Berkeley/LBNL
- 9:15 Matteo Frigo, Cilk Arts
- 10:00 Break
- 10:30 Jeremy Johnson, Drexel
- 11:15 Franz Franchetti, CMU
- 12:00 Lunch on your own (per diem)

Processors 1

- 13:30 Richard Johnson, NVIDIA
- 14:15 Adrian Tate, Cray
- 15:00 Break
- 15:30 Sam Williams, UC Berkeley/LBNL
- 16:15 Michael Houston, Stanford
- 18:00 Dinner Reception

Day 2 - Tuesday, July 10

- 8:00 Continental Breakfast

Libraries 2 (Dense LA etc)

- 8:30 Paolo Bientenisi, Duke
- 9:15 Nikos Pitsianis, Duke
- 10:00 Break
- 10:30 Dan Terpstra, U. Tennesse
- 11:15 Clint Whaley, UT San Antonio
- 12:00 Lunch on your own

Compilers

- 13:30 Keith Cooper, Rice
- 14:15 Rudi Eigenmann, Purdue
- 15:00 Break
- 15:30 Mary Hall, USC/ISI
- 16:15 Jackie Chame , USC/ISI
- 17:00 Break
- 18:00 Dinner on your own
- 19:30 **Experiences, controversies, discussion**

Agenda Days 3 and 4

Day 3 - Wednesday, July 11

- 8:00 Continental Breakfast

Libraries 3 (Sparse LA)

- 8:30 Richard Vuduc, LLNL/GeorgiaTech
- 9:15 Kaushik Datta, UC Berkeley
- 10:00 Break
- 10:30 Jim Demmel, UC Berkeley
- 11:15 Experiences, discussion
- 2:00 Lunch on your own
- 13:30 Enjoy the Snowbird area
- 15:00 Break

Processors 2

- 15:30 Mattan Erez, UT Austin
- 16:15 Michael Frank, AMD
- 17:00 Break
- 18:00 Banquet

Day 4 - Thursday, July 12

- 8:00 Continental Breakfast

Tools for Autotuning

- 8:30 Qing Yi, UT San Antonia
- 9:15 Guojing Cong, IBM
- 10:00 Break
- 10:30 Dan Terpstra, U. Tennessee
- 11:15 Yaoqing Gao, IBM
- 12:00 Lunch on your own

Wrapup Discussion

- 13:30 Community building, engaging applications
- 15:00 Break
- 15:30 Informal discussions with specific subgroups
- 17:00 Workshop ends