Component Integration and Optimization

For High Productivity and Performance

Ken Kennedy

Rice University

http://lacsi.rice.edu/review/2004/slides/components.pdf

Participants

- LANL
  - Staff: Craig Rasmussen
  - Student: Christopher D. Rickett
- Rice
  - Faculty/Staff: Ken Kennedy, Bradley Broom*, Zoran Budimlic, Keith Cooper, Arun Chauhan*, Rob Fowler, Guohua Jin, Tim Harvey, Chuck Koelbel, John Mellor-Crummey, Steve Reeves, Linda Torczon
  - Students: Raj Bandyopadhyay, Alex Grosul, Mack Joyner, Cheryl McCosh, Apan Qasem, Todd Waterman, Rui Zhang, Yuan Zhao
- Tennessee
  - Faculty/Staff: Jack Dongarra, Keith Seymour
  - Students: Haihang You, Jelena Pjesivac-Grbovic,and Jeffery Chen
- Houston
  - Faculty: Lennart Johnsson
  - Students: Ayaz Ali, Purvi Shah, Haiyan Teng

Outline

- Component Integration Systems
  - Support for the maintenance and optimization of component libraries
  - High-productivity languages
- Retargetable High Performance Components
  - Automatic tuning of components for specific computing platforms
  - Design of adaptive components
- Application Drivers from LANL Weapons Program
  - Marmot, Telluride, Project A
- Previous Projects, Phased Down
  - High-Level Java Optimization
  - Program Preparation for Heterogenous Computing Environments (e.g., Grids)

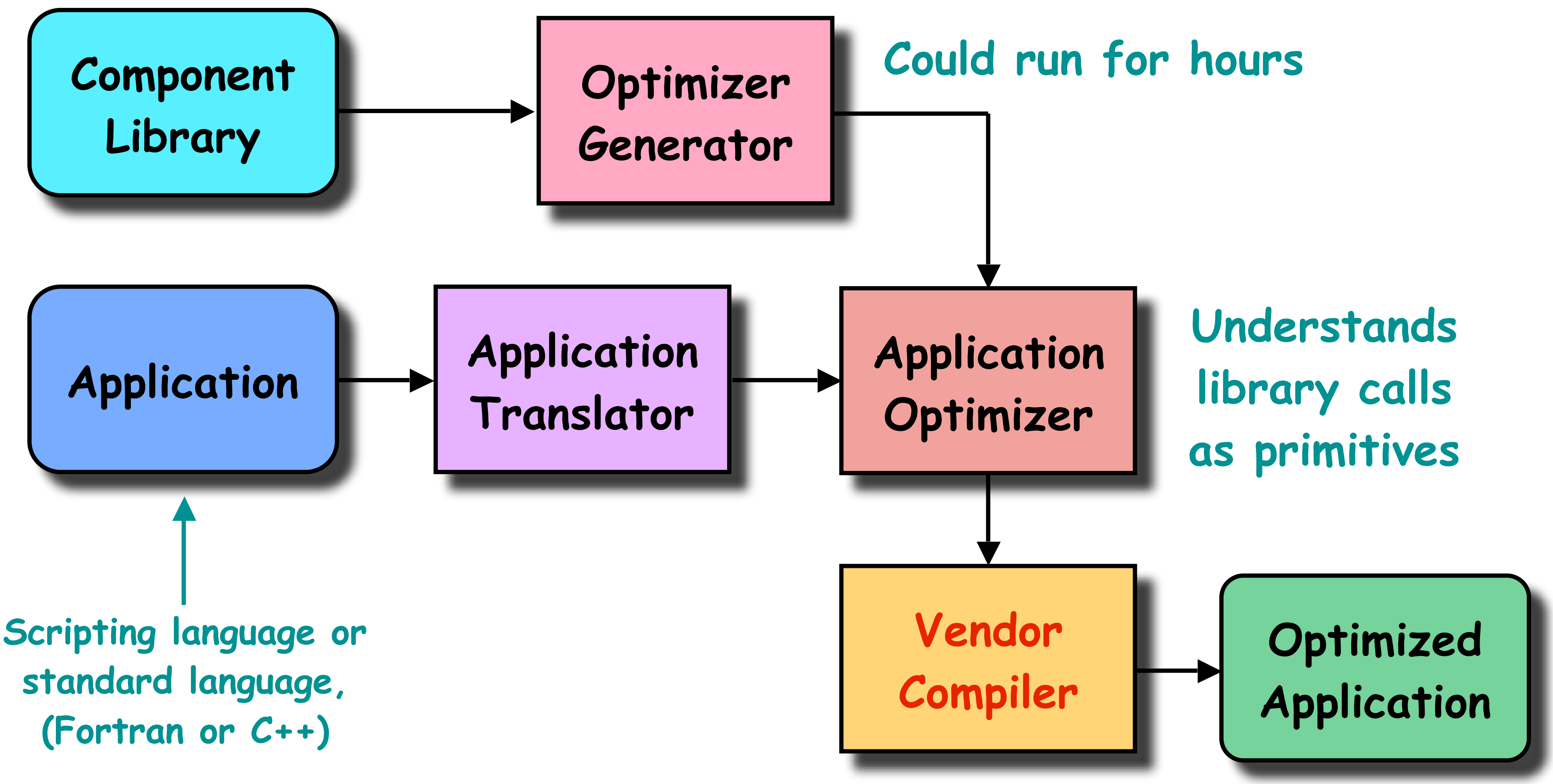
Component Integration System

- Component integration systems are important productivity tools
- Programs constructed from them are often slow
  - No context-based code improvements can be applied
- Claim: Telescoping languages can address this problem
  - Can be applied to construct component integration systems that yield high-performance applications
  - Can make components usable in contexts that have been previously considered impractical
- ASC Relevance
  - Component-based software is critical for productivity and reliability
  - Performance must be high for software to be usable
  - Useful to prototype in high-productivity language (Python, Matlab)

Component Integration Challenge

- Integration of different component libraries that
  - Implement data structures (e.g., sparse matrices)
  - Implement functions on data structures (e.g., linear algebra)
- Problem: Performance
  - High function overhead for data structure access (frequently invoked)
  - Need optimization for special contexts
    - e.g., invocation in loops
- Claim: Telescoping languages can handle this well
  - Advance generation of specialized entries
  - Transformation pass to perform substitution

Telescoping Languages



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Telescoping Language Advantages

- Optimized script compilation times can be reasonable
  - Investment in library analysis speeds script optimization
- High-level optimizations possible
  - Exploit library designer's knowledge of routine properties
  - Specialize library routines during optimizer generation to exploit expected calling sequences
    - Apply high-level transformations based on identities
    - Factor and/or fuse library primitives as appropriate
- User retains substantive control over performance
  - Mature code can be built into a library, annotated with properties to aid optimization and fed to library compiler
- Reliability can be improved
  - No hand coding to context

What We Have Done

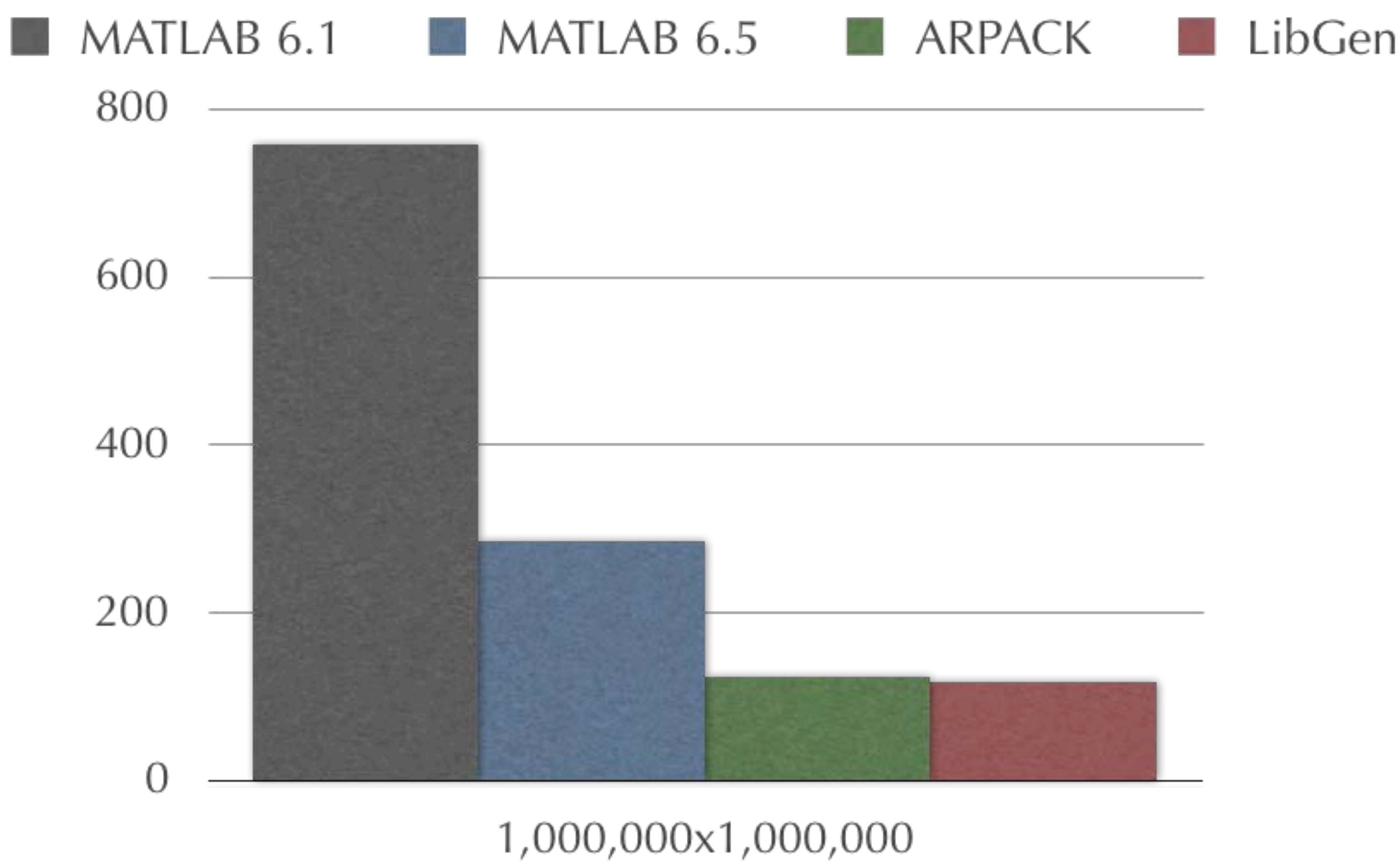
- Developed base-language compiler technology
  - Type inference: Key to generation of C or Fortran from Matlab, S, or Python
    - Useful even if C++ or Fortran is your scripting language
- Conducted preliminary studies
  - Matlab SP (Signal Processing), LibGen (library generation)
    - Six papers, one Ph.D., two Master's
  - R compilation (funded separately by DOD)
- Demonstrated benefits of telescoping languages as component integration system (via LibGen)
- Developed strategy for generalized data structures
  - Including addition of parallelism to scripting languages (funded by ST-HEC program from NSF/DARPA)
- Met with Marmot team to explore collaboration opportunities

Library Generator (LibGen)

- ARPACK
  - Prof Dan Sorensen (Rice CAAM) maintains ARPACK, a large-scale eigenvalue solver
- Methodology
  - He prototypes the algorithms in Matlab, then generates 8 variants in Fortran by hand:
    - {Real, Complex} x {Symmetric, Nonsymmetric} x {Single,Double}
    - Dense vs Sparse handled by special interface
- Could this hand generation step be eliminated?
  - Answer: YES
  - Key technology: Constraint-based type inference
    - Polynomial time algorithm to compute type jump functions

      Map input types to variable types

LibGen Performance



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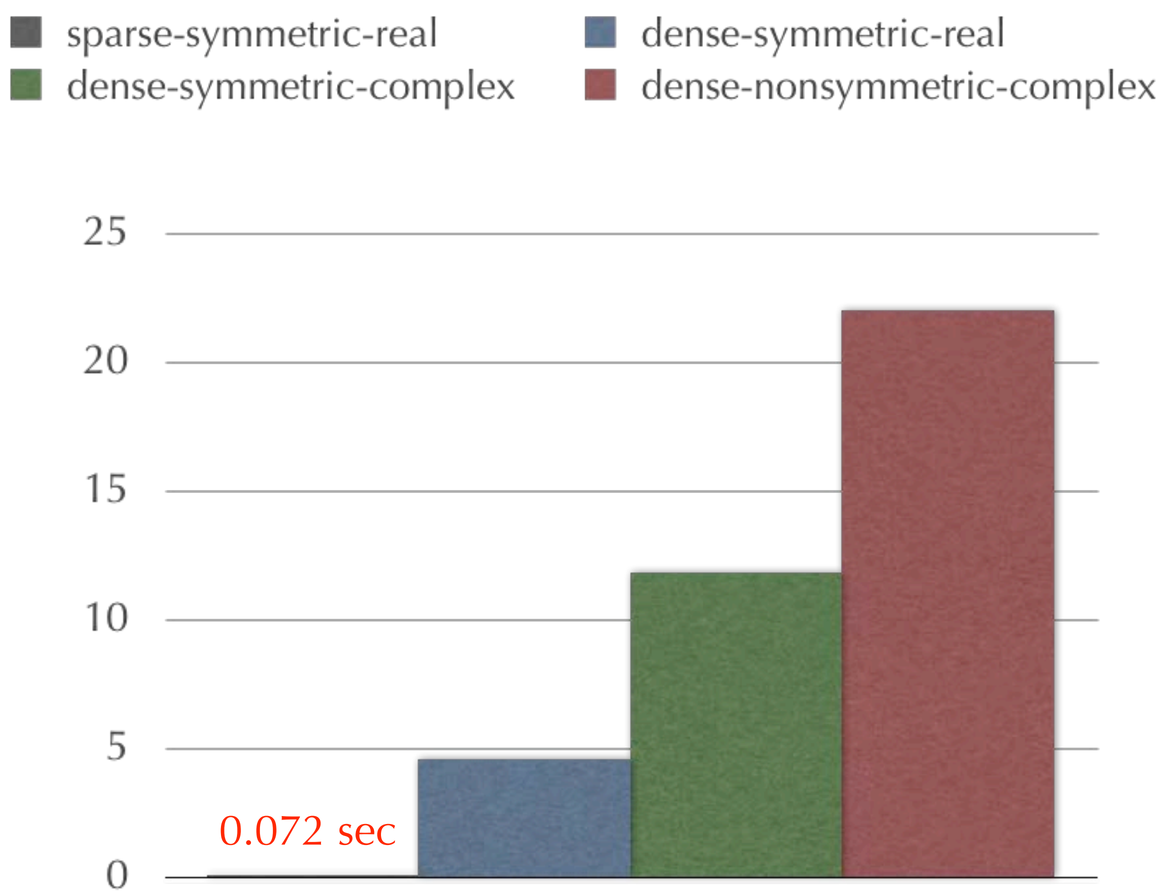
Value of Specialization



Distribution and Parallelism

- Strategy: Add distribution to Matlab arrays
  - Standard libraries plus user-implemented distributions
  - Distribution libraries (e.g. block) packaged with language
- Telescoping compiler optimizes distribution accesses
  - Mimics standard optimizations, such as vectorization of accesses
    - This is simply procedure strength reduction
- Parallelism by HPF-style computation generation
  - Computation performed close to data
  - Rice has strong HPF technology in place
  - HPF compilation (slow) applied only to components (not to script)
- Project spun out into NSF ST-HEC proposal
  - Funded through DARPA HPCS

LACSI Interactions

- Priorities and Strategies Meetings
  - Inputs from Steven Lee and Ken Koch were pivotal in direction change
- Attended Common Component Architecture (CCA) Workshop
  - LACSI Symposium 2002
- Initial Components Workshop (April 16-17, 2003)
  - Organized by Craig Rasmussen
- Discussions with Marmot Group
  - Monterrey Methods Workshop (March 16-18, 2004)
  - Components Workshop at LANL (June 24, 2004)
    - Developed an outline plan for collaboration

What We Plan to Do

- Seek (and solve) component integration challenge problem
  - Based on work from ASC applications
  - Emphasis on efficiency of frequent component-crossing
    - Integration of data structure and function
- Continue interactions with Marmot Project
  - Goal: build tools to help them on their second or third iteration
    - Build on work on component integration and optimization of object-oriented languages
- Explore opportunities in other ASC codes
- Relevance to ASC
  - Success will make it easier to use modern component-based software development strategies in ASC codes
    - Without sacrificing performance

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Automatic Component Tuning

- Participants: Four Groups within LACSI
  - Tennessee: Jack Dongarra
    - Collaboration with LLNL ROSE Group (Dan Quinlan, Qing Yi)
  - Rice: Ken Kennedy and John Mellor Crummey
    - Students Apan Qasem and Yuan Zhao
  - Rice: Keith Cooper, Devika Subramanian, and Linda Torczon
    - Students Todd Waterman and Alex Grosul
  - Univ of Houston: Lennart Johnsson
    - Students Ayaz Ali, Purvi Shah, Haiyan Teng

Automatic Component Tuning

- Goal: Pretune components for high performance on different computing platforms (in advance)
  - Models: ATLAS, UHFFT
  - Generate tuned versions automatically
- Strategy: View as giant optimization problem with code running time as objective function
  - For each critical loop nest:
    - Parameterize the search space
    - Prune using static analysis
    - Employ heuristic search to find optimal point and generate optimal code version
  - Typical optimizations:
    - Loop blocking, unroll, unroll-and-jam, loop fusion, storage reduction, optimization of target compiler settings, inlining, optimization of function decomposition

Automatic Tuning

- **Successes**
  - Experimental infrastructure
    - LoopTool, MSCP, ATLAS2, CODELAB
  - Large-scale experiments
  - Principles demonstrated
    - Effectiveness of heuristic search
  - Papers published
    - Seven refereed publications and one technical report (see web site)
- **Relevance**
  - Dramatically increases productivity of scientific programming
- **Connections to ASC**
  - Sweep3D, Marmot, Truchas, Code A

Some Previous Accomplishments

- JaMake Java Framework
  - Collaboration with CartaBlanca Project
  - Performs object inlining on arrays of objects
    - Overcomes the cost of using full OO polymorphism
    - Achieved 80% improvement on the LANL Parsek code
  - Results apply to C++ and Python

  Attracted NSF funding, published 6 refereed papers

- Grid Research
  - Drove performance prediction research
  - Effective performance-model based scheduling
  - VGrADS: NSF ITR (Large)
  - Ideas for Grid in a box
    - Many future supercomputers will have heterogeneous computing components: good scheduling will be critical for performance

Summary

- **Component integration languages and frameworks**
  - High Level: Matlab, S, Python plus component libraries
  - Low Level: C, C++, Fortran
- **Compilation technology**
  - Type inferencing to drive translation to C or Fortran
  - Telescoping languages to pre-optimize libraries
  - Parallelism in scripting languages
    - Parallelism based on distribution
- **Component Autotuning**
  - Goal: ATLAS-style automatic tuning for generalized applications, UHFFT-style automatic tuning for decomposable (library) components
  - Exploring heuristic search and static search-space pruning
- **Technology Transfer**
  - Focus component integration on problems arising from Marmot project
  - Automatic tuning applicable to general languages