Overview of Research in the Bernoulli Group

Keshav Pingali, Paul Stodghill

Grigor Bronevetsky, Jim Ezick,
Rohit Fernandes, Daniel Marques,
Kamen Yotov

Department of Computer Science

Cornell University

Outline

- Fault-tolerance
  - Compiler Transformations for Fault-tolerance
  - MPI/FT
  - Other work
- Databases
- Adaptive Compilers
- Collaborations

System-level adaptivity

- Increasingly important for high-performance computing
  - Simulation as the third mode of discovery
  - → explosion of scientific computing
- Adaptive computing
  - Changing resource demands
- Fault-tolerance
  - Better networking
  - → Collaboration, Resource Sharing
  - → Distributed computing

State of the art

- Research in distributed systems
  - General purpose, transparent reliability for user applications
  - Implemented at the (operating) system level
  - $\therefore$ few assumptions about the applications
- Research in restructuring compilers
  - Program analysis and transformations
  - Irregular and parallel applications

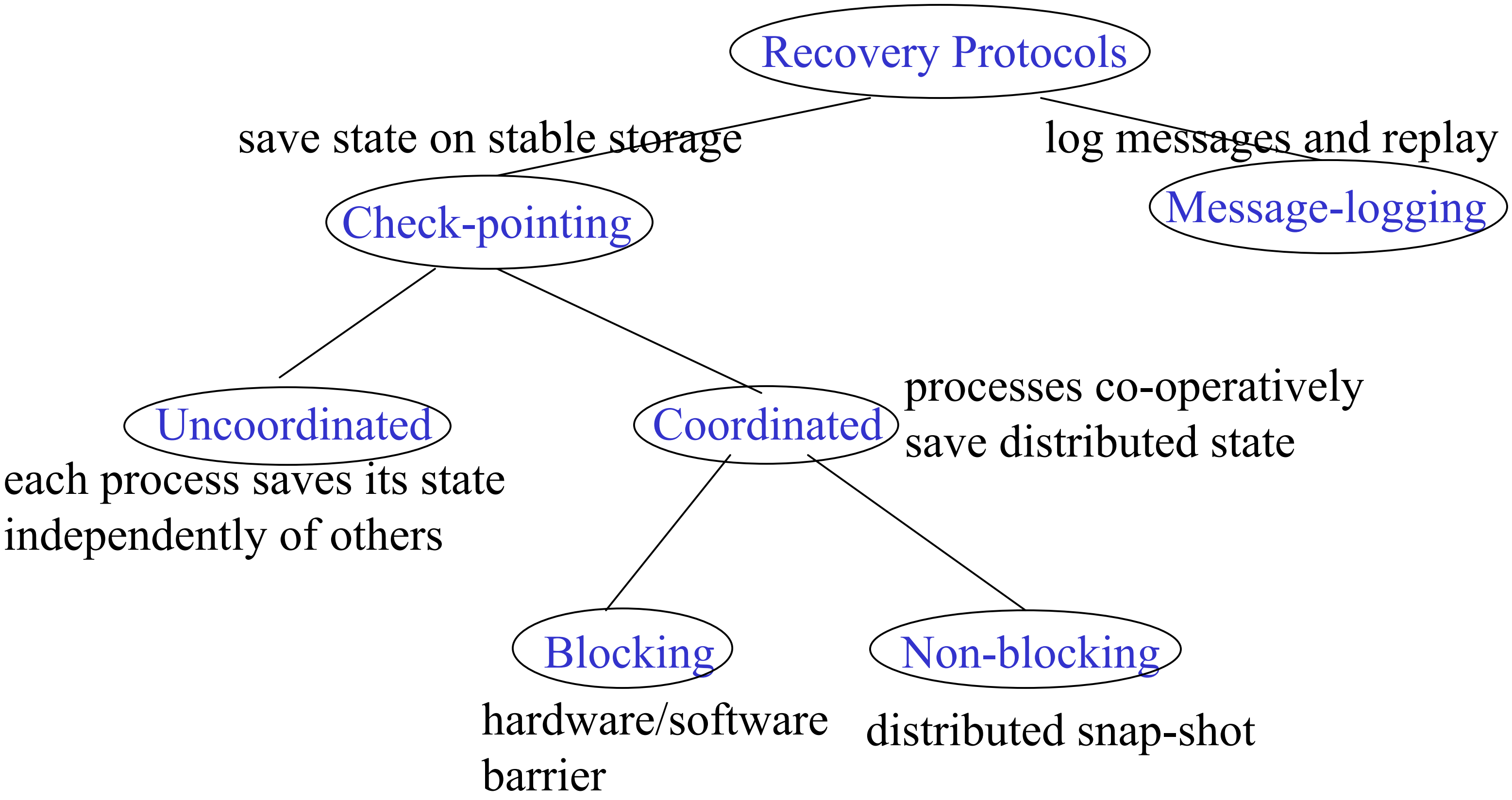
Our approach

- Goal:
  - Transparent reliability
    with lower overhead
- Lower overhead by
  - exploit structures of applications
- Transparent, automatic by
  - using program transformations (ie, compiler aided)
- Compiler + Run-time system = a feasible solution

Current work

- Exploiting determinism
  - Most scientific codes are deterministic (or might as well be)
  - Runtime: Deterministic and Non-deterministic message logging protocols
  - Compiler: insert code to switch between
- Exploiting inherent synchronization
  - Many scientific codes have global synchronization
  - Runtime: Uncoordinated, Block and non-blocking coordinated checkpointing
  - Compiler: find and leverage global synchronization
- Preliminary experiments: workable and practical

Classification of recovery protocols for distributed memory computations



Program transformations for application-level checkpointing

- Dan Marques
- Program transformations for
  - C + user annotations
  - Globals, Locals, stack
- Future work
  - Heap objects
  - robustness

```
int fib(int a)
{
    int b; int c[5];

    if (a <= 1)
        return 1;
    else{
        int temp1;
        int temp2;
        temp1 = fib(a - 1);
        b = temp1;
        /* TAKE-CKPT-HERE */
        temp2 = fib(a - 2);
        b = b + temp2;
    }
    return b;
}
```

Program transformations for application-level checkpointing (cont.)

```
int fib(int a)
{
    int b; int c[5];

    if (_CKPT_MODE) {
        // Restore locals from disk
        switch(_CKPT_TMP_LABEL) {
        case 1: goto LABEL_1;
        case 2: goto LABEL_2;
        case 3: goto LABEL_3;
        }
    }

    if (a <= 1)
        return 1;
    else{
        int temp1; int temp2;
        // Push locals to stack'
    LABEL_1:
        temp1 = fib(a - 1);
        // Pop locals from stack'
        b = temp1;
        // Push locals to stack'
        // Checkpoint: write stack' to disk.
    LABEL_2:
        if(_CKPT_MODE){
            _CKPT_MODE = 0;
            fclose(_CKPT_FILE);
        }
        // Pop locals from stack'
        // Push locals to stack'
    LABEL_3:
        temp2 = fib(a - 2);
        // Pop locals from stack'
        b = b + temp2;
    }
    return b;
}
```

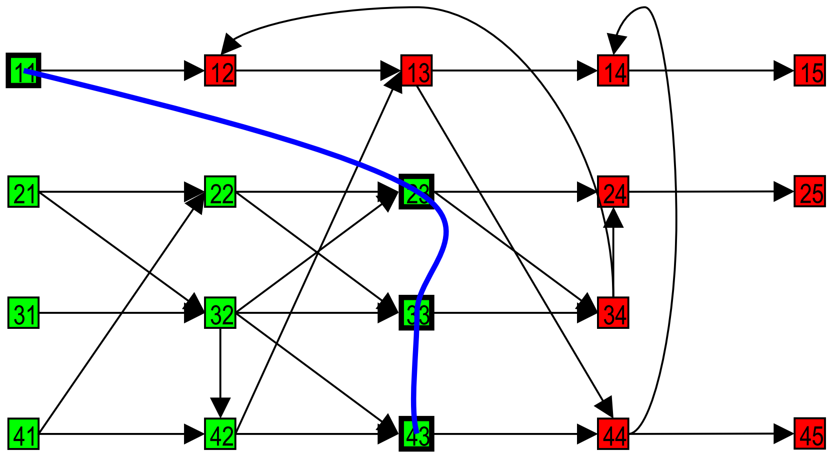
Program Analysis for application-level checkpointing

- Jim Ezick and Dan
- If i0..i99 are unchanged at L102, then L0..L99 can be used to reinitialize
- Save minimal data to checkpoint (ie, k)
- Construct recovery script to reinitialize remaining data
- “compiler-theoretic” view of the problem (dominator trees)
- Tradeoff b/w size of checkpoint and recovery cost.

```
L0: i0 = 0;
        .
        .
        .
L99: i99 = 0;
L100: k = 0;
L101: while (k < 1000)
L102:         // check point here
L103:         print f(k,i0,...,i99)
L104:         k = k+1
```

Improved Algorithms for Finding Best Recovery Lines

- Kamen Yotov
- Uncoordinated Checkpointing and (Optimistic) Message Logging
- Simplified the classic algorithm (4 colors to 2)
- Because it's based on DFS, it's easier to understand and implement.



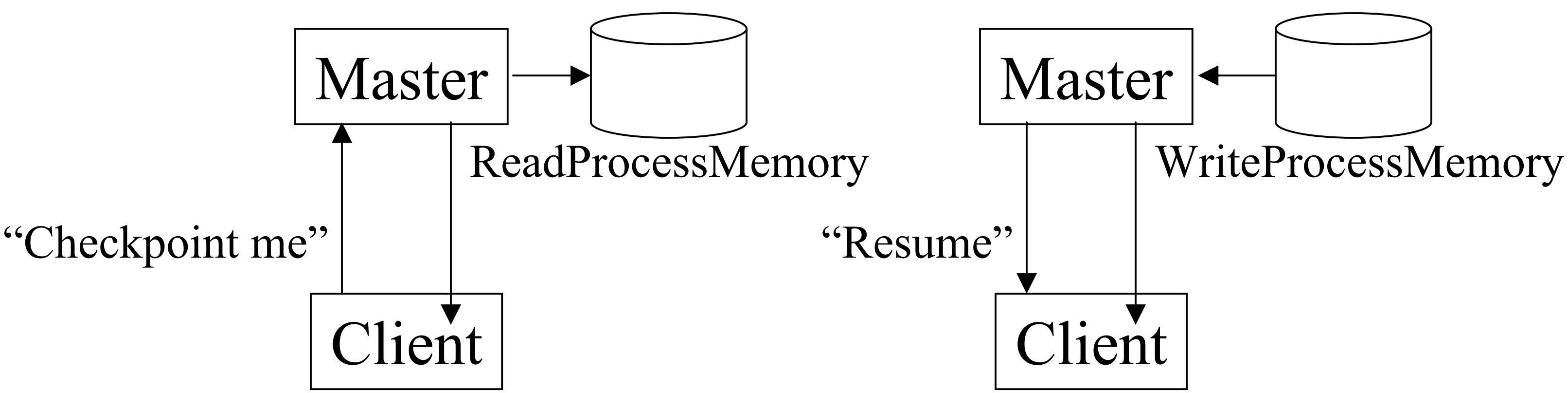
MPI/FT

- Sequential checkpointing is working
- MPI “hooks” are implemented
- Engineering difficulty in getting the two to work together.

MPI/FT (cont.)

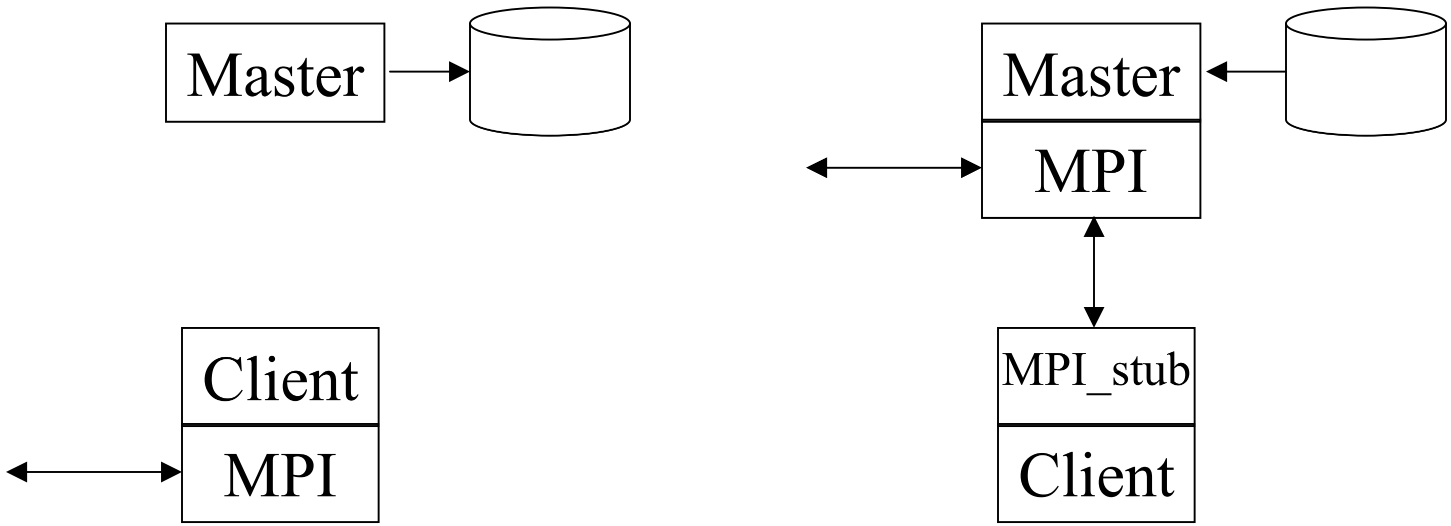
- Sequential checkpointing architecture
- Challenge – isolate client state from system state

Checkpointing Restore



MPI/FT (cont.)

- What should the MPI architecture be?



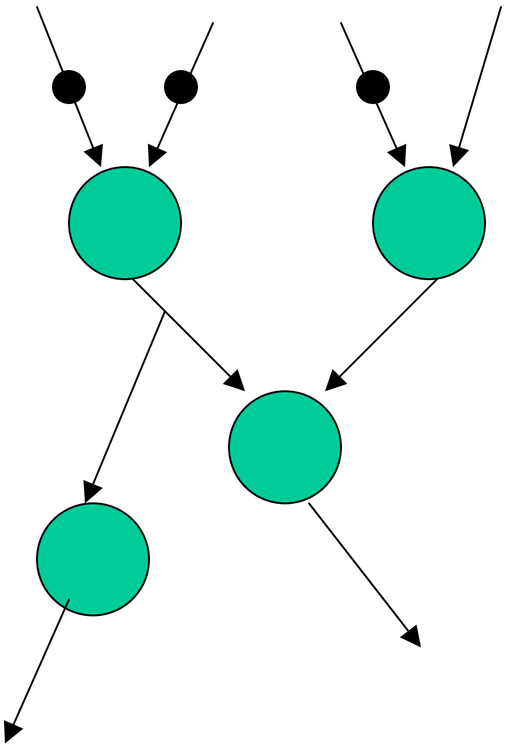
- "Tangled" MPI state
- Poor performance?

Programming with Web Services

- Not implementing the web services themselves (component program)
- Rather, programming with web services as external components (control program)
- Assumptions,
  - A request to a web service can take a very long time to complete.
  - Failures are possible (likely) during the execution of the control program

Dataflow Machine Model

- c.f. Von Neuman
- Machine is collection of computational nodes and dataflow edges
- Values flow along edges as tokens
- Nodes “fire” when tokens available on all in edges



Historical dataflow machines

- Properties
  - Inherently parallel
  - Latency tolerance
- In the literature
  - Thread models (e.g., fibers)
  - Dependence Flow Graphs (DFG's)
- Inspired architectures
  - Monsoon
  - Tera, Earth/Manna
- Inspired programming languages
  - Id, Id Noveau
  - SSISL

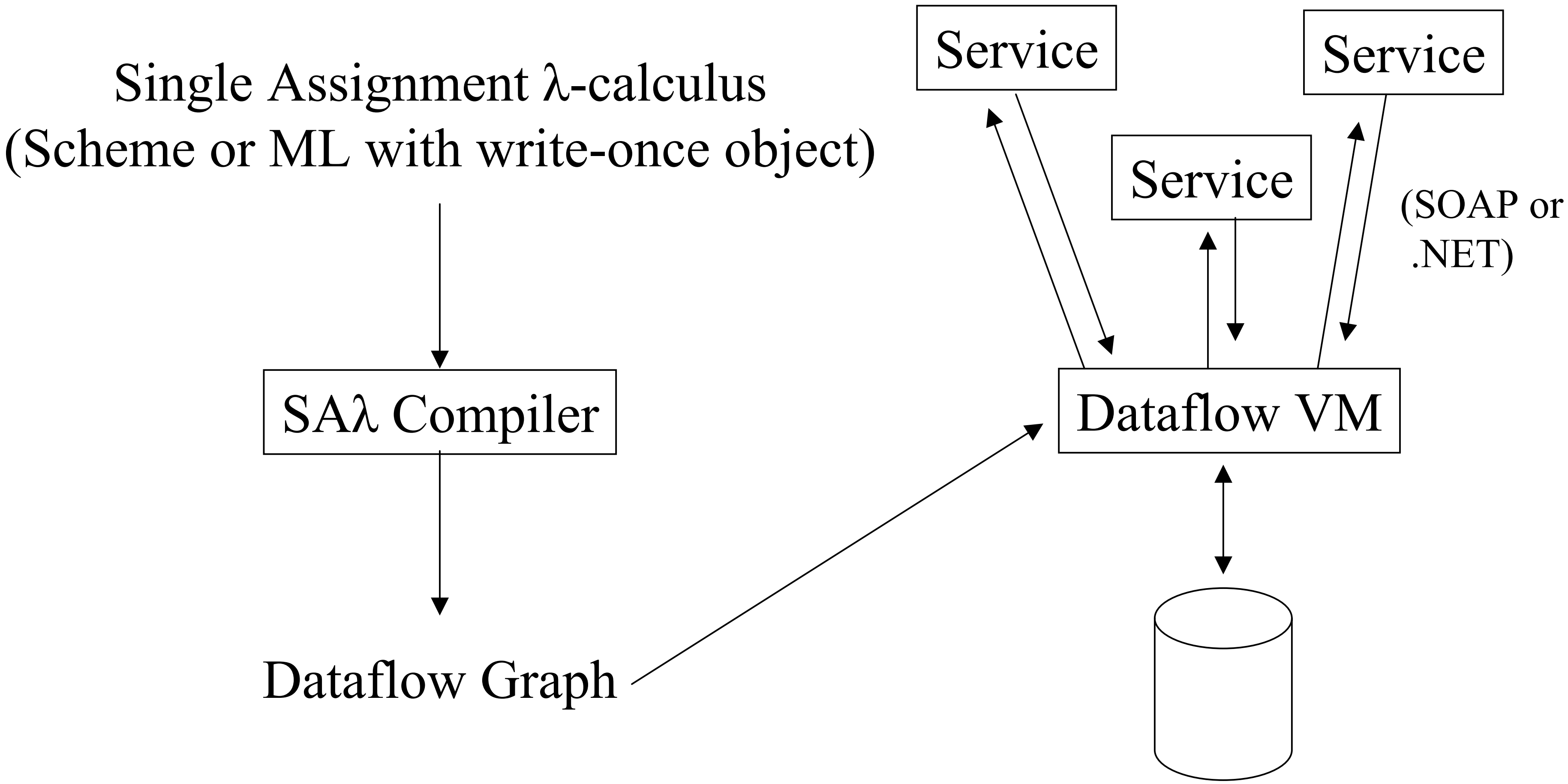
Dataflow – the dark side

- Dataflow machines are slow
  - Custom chips
  - Designed for throughput, not peak
- Dataflow languages are hard
  - Scheduling for conventional machines is hard
  - Programmers are used to thinking about state
  - Legacy code without a killer app

Perfect for Web Services

- Control program for web services
  - Latency and fault tolerance is key
  - Efficient scheduling isn’t (b/c latencies are unpredictable)
  - Control programs are small and are novel

Architecture for Programming Web Services



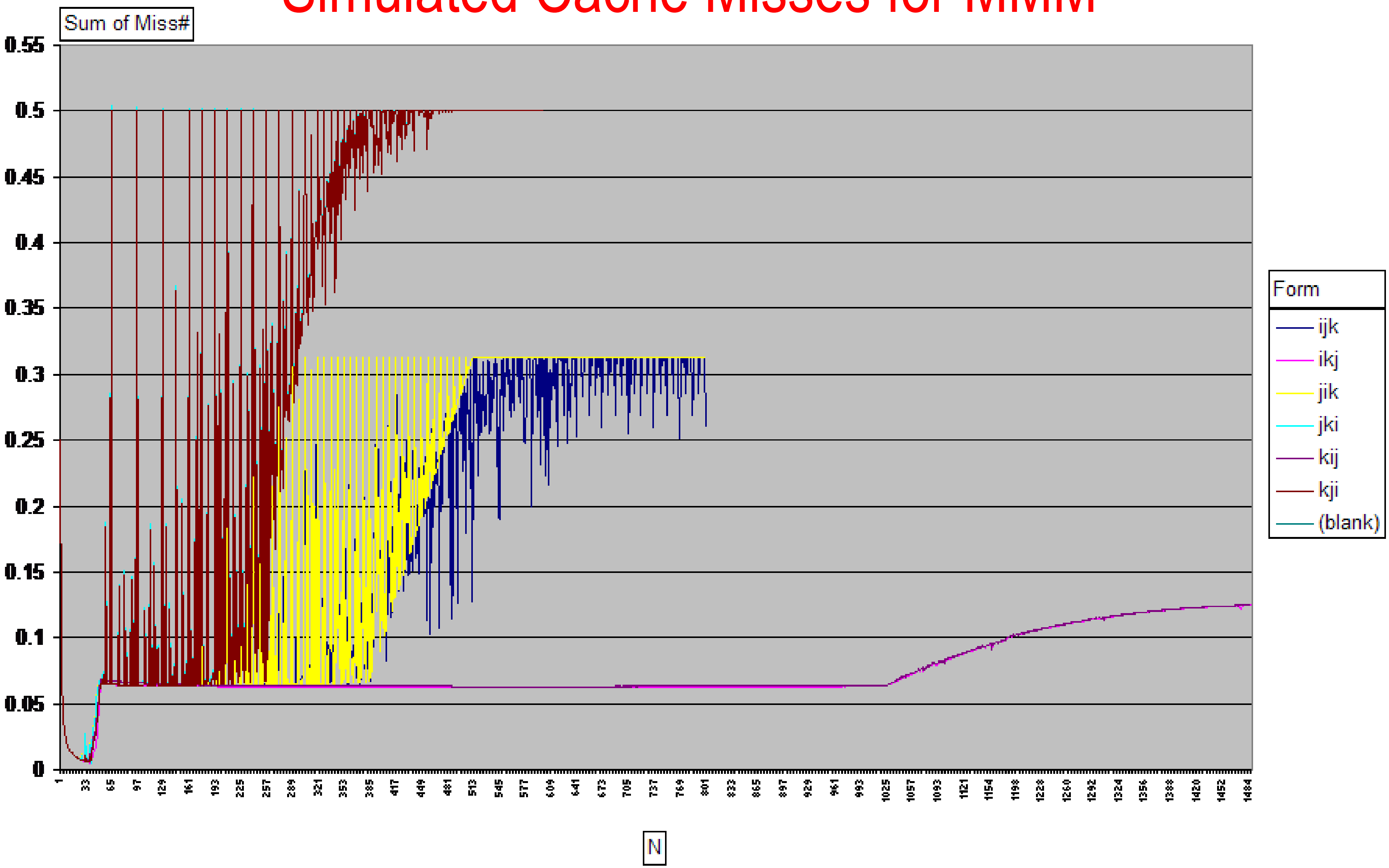
Adaptive Compilation

- Empirical Optimization – use experiments to guide parameter selection
- ATLAS – MMM optimized for one cache level
  - Parameters – unrolling, block-size, etc.
  - Experiments run for hours or days
- Memory Hierarchies are very deep (more than 3-levels)
  - Brute-force approach is not practical

Adaptive Compilation (cont.)

- Our approach
  - Use performance models to find neighborhood
  - Use experimentation to find optimal parameter values
- Benefits
  - Much faster than ATLAS-style
  - Therefore can tackle multiple levels of memory hierarchy.
- How to develop models
  - By hand
  - By machine learning

Simulated Cache Misses for MMM



Discovering cache parameters

- Models are based upon certain cache parameters
  - Cache-size
  - Line-size
  - Associativity
  - Miss penalty
- Remember HW#1?
  - Looking at machine learning and heuristic methods.

History

- 80% of the code of a typical business application deals with data manipulation (access, selection, I/O, transformations)
- Only 20% problem-oriented code
- Late 60s: How to reduce the not problem-oriented part?

Problems w/ Files

- File = dumb sequence of bytes (stream-oriented)
- Change in file format incurs costly source code changes (each function has to “know” the data layout)
- No guarantees for:
  - Data integrity
  - Referential Integrity
- No data manipulation language (DML)

Problems w/ Files (cont.)

- Poor interoperability
- No default support for:
  - Fault tolerance
  - Transactions

Problems solved in current generation RDBMS!

Microsoft SQL Server

Informix Dynamic Server (IDS)

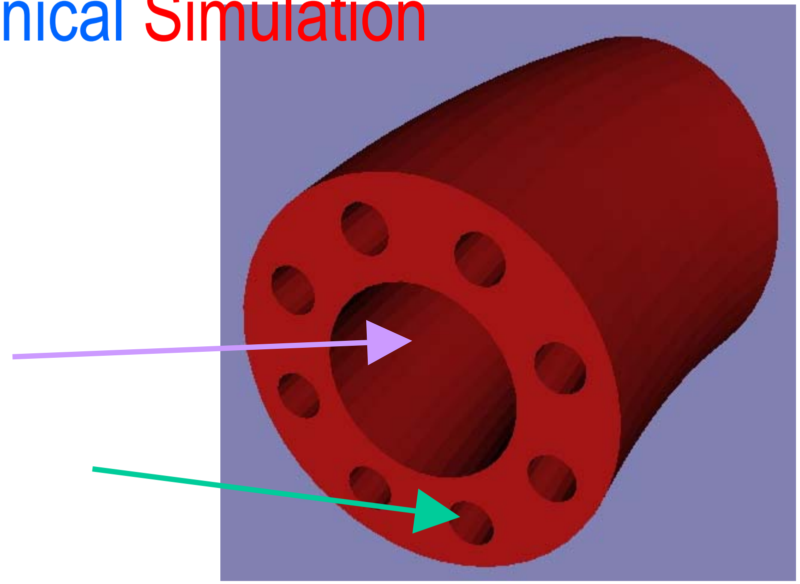
DB2 Universal Database

ORACLE

Solid Models

- Large unstructured data sets (and relations=structure) involved: Topology, Geometry, Mesh(es), Material properties
- Distinct (e.g. pre- and post-processing) phases with different access patterns
- Cannot be effectively handled without a querying language!

Coupled Thermo-Mechanical Simulation



- Heat conduction
  - Heat fluxes on the central hole from MSU
  - Fixed temperature (500K) for the cooling holes
- Solve for Temperature, spawn off wavelet analysis
- Coupling
  - Thermal stresses
  - Temperature dependent Young's modulus and Poisson ratio
- Deformation
  - Pressures and shear stresses on the inner hole from MSU
  - Fixed displacement on one end surface
- Solve for displacement

Query Example

```
SELECT A.m_tet_id
  FROM
      (SELECT m_tet_id
         FROM MVerticesOfMTetrahedron
         WHERE m_vertex_id IN
           (SELECT m_vertex_id
              FROM MVerticesOfMTrianglesOnTSurface
              WHERE m_triangle_id IN
                (SELECT m_triangle_id
                   FROM MSU_wall_conditions)
           )
         GROUP BY m_tet_id
         HAVING COUNT(m_vertex_id) = '3‘
      ) AS A
    JOIN
      TPartitioning AS B ON A.m_tet_id = B.m_tet_id
  WHERE B.partition = ‘my_MPI_rank';
```

Adaptivity

- Modeling
  - Coupling
- Algorithmic
  - Identify hotspots and stress concentrations
  - Explore different discretization techniques
- “FEM backend”
  - H- and P-adaptivity
  - Different solvers and preconditioners
- Database
  - Query granularity

Advantages

- Database preserves a global view in a distributed simulation
- Reduced code size (SQL statements = strings, ODBC calls)
- The power of `SELECT`
- Interoperability (ODBC, OLE DB, ADO, HTTP, XML, …)
- Higher concurrency

Collaborations

- Cornell
  - Paul Chew, Steve Vavasis, Bart Selman, Carla Gomes
  - Cornell Fracture Group, Civil Engineering
  - Cornell Theory Center
- Engineering Research Center, Mississippi State University
- College of William and Mary
- Dept of Comp Sci, UIUC
- IBM TJW