Major Trends in Information Technology Research

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History of Innovations

1944: Mark 1
1948: SSEC
1956: RAMAC
1957: FORTRAN
1966: One-Device Memory Cell
1967: Fractals
1970: Relational Database

1971: Speech Recognition
1973: Winchester Disk
1979: Thin Film Recording Heads
1980: RISC
1994: SiGe
1993: RS/6000 SP
1996,97: Deep Blue

1997: Copper Interconnect Wiring
1998: Silicon-on-Insulator
1998: Microdrive
2001: Nanotube Transistor
2002: Millipede
2002: Molecule Cascade Logic Circuit
I/T Research at This Time

- Fantastic opportunity to make progress and value in new domains, due to:
  - Pervasive communication
  - Computational capability
  - Building blocks developed over 50+ years
  - Societal & Institutional acceptance

- Many core computer sciences challenges remain:
  - Making systems work *easily* and *robustly*
  - Staying on traditional performance curves given likely decline in rate of frequency scaling
Computer Science-related Work

IBM Research Division Breakdown

- Computer Architecture, Systems & Storage Systems
- Distributed Computing
- Information & Interaction
- Solutions to Business Problems
- Programming Models & Tools
Select Research Foci

- Technology (Modular)
- Dynamic e-Business
- Next Gen Web
- Grid
- Utilities
- Autonomic Computing
- Intelligent Information
- Continual Optimization
- Federated Identity
- On Demand Business Value
- People Proxies
- On Demand Operating Environment

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A Few Topics

- Continual Optimization
- Unstructured Information Management
- Blue Gene
- Autonomic Computing
Continual Optimization
Reduce Inefficiency in the World’s GDP

- Create strategies for *optimized integration* based on a methodology for performance transformation backed by software tools, standard business models, computational assets, deep analytical skills & deep industry/process insight.
Premise: Continual Optimization

- Almost everything can almost always be connected to a computer network
- Therefore, we can measure most anything most all the time
- We can effect change at geometrically declining costs
- With fast processors, and good optimization algorithms, the opportunity for optimization is great
- Continual optimization could fundamentally change how we might lead our lives
Just as Computing has Evolved

- **Batch processing** → **Individual transactions**
- **Ab initio processes** → **State based processes**
- **Scheduled computations** → **As needed, triggered by events**
- **Relatively expensive** → **Virtually free**
- **Independent processes** → **Interacting processes**
- **Back office** → **End users**
- **Rigid linear workflow** → **Adaptive, state-based workflow**
- **Islands of computing** → **Global networking**
Analytic Computing is Also Evolving

enabling new business applications and business models

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United Airlines 8 Fleet Problem
Optimization Examples

- Season tickets in advance
- Pricing set above MC and to clear the market
- Ad hoc inventory management
- Static binding of resources
- Approximate production optimization
- Opportunistic interpersonal scheduling
- Search for a restaurant while driving on the road
- Notification when you want of events you like
- Pricing based on utility of consumer
- Scientific inventory management
- Dynamic resource binding
- Exact production optimization
- Dynamic interpersonal scheduling
- Be informed of nearby restaurants meeting criteria
Dinner and a Show w/Continual Optimization

- Consumers: Express preferences, receive complete offers
  - Show, dinner reservations, travel route and parking for a single price
  - All can be reserved ahead of time
  - Special last minute deals available
  - Monitored and re-optimized dynamically (according to customer preferences, of course)

- Providers: Dynamically allocate and aggregate
  - Allocate multiple resources consistently
  - Dynamically manage inventory across multiple channel
  - Sell seats/tables in categories & do late binding of specific seats
  - Supply reservations for parking, travel lanes, etc.
  - Monitor availability & re-deploy dynamically in response to disruptions
  - Slack management
A Real Example: Limo Scheduling & Dispatching

- Executive class ground transportation
- Service by owned resources in 7 cities and worldwide through affiliates
- Pride in excellent service record of 98-99% on-time pickups; but at cost of 10-12% request refusal rate at peak times and low utilization of resources
- Customer contacted IBM Research through IBM Innovation Center
- Scheduling problem recognized as a potential match for Continual Optimization initiative
- Integration, middleware, project management, etc. from IBM Business Consulting Services
- Original driver utilization ~10% below optimal, believed to cost tens of millions of US$/year
- Our solution within 1.5% of optimal
Project Overview

- Watson Optimization Center developed a Continual Optimization scheduling/dispatching tool for LimoCo
  - Optimizer code delivered in 2Q02
  - Live tests of the system in December

- Project size
  - 5600 lines of custom code
  - + existing optimization libraries
  - + databases, integration and user interfaces by BCS

- Success criteria
  - Original driver utilization ~10% below optimal, believed to cost tens of millions of US$/year
  - Our solution within 1.5% of optimal
Issues: Communications & Data Infrastructure

- Data
- Transaction management
- Modular, distributed architecture
- Privacy
- Availability
- Scale
- Organizational autonomy
- Ease of use pervasive devices | HCI
- Most significant problem: Business Process Modeling and Automated Integration
Applied Mathematics Research

- New Applications of Known Models/Algorithms
  - Shortest path problem (single car routing, static network)
  - Time dependent shortest path (speed depends on time of day)
  - Multiple vehicles with multiple origin-destinations
  - Other resources (parking, restaurant) can use job shop scheduling. Many jobs & machines, but nice structure & few ops/job

- Stochastic Optimization

- Non-linear Integer Programming
Use of simulation & optimization tools and "active real-time" data for strategic business decisions.

**Mission Control Center**

- Manage decisions cooperatively
- Optimize decisions based on realtime data
- Real-time simulations followed by capability activation and feedback
Unstructured Information Management
Unstructured Information Management

- UI / UCD
- Visualization
- Personalization
- Context Awareness
- Dialog Management

- Applications
- Content Management (privacy)
- Expert Location
- Text Mining
- Alert Systems
- Translation
- Question Answering

- Analysis Technologies
- Clustering
- Classification
- Summarization
- Feature Extraction
- Deep Parsing
- Trans-lingual processing
- KRS ontologies, DM
- Inference Engines
- Glossary Extraction

- Information Retrieval
- Search/Retrieval (indexing)
- Tokenization
- Doc. filters
- Navigation (Taxonomies)
- Language id.
- Shallow parse

- Data Access
- Document Collectors (crawlers, Spiders)
- Content Management (Access)

- Data Sources
- Structured
- Unstructured
- Tagged
- DB
- Files
- Networks
- Sensors
- Agents

- Foundation
- Tooling (AD, System config+mgmt, Component Development)
- Data (training, test)
- Industry Standards

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UIMA: Common Middleware Infrastructure

Bringing order from this potpourri

Core Capabilities
- Process large collections of unstructured artifacts (i.e., “documents”)
- Process multiple languages
- Index documents in terms of key words, classes, semantic content etc.,
- Quickly find and rank documents based on queries for literal and semantic content
- Discover plug-ins based on their capabilities
- Support ease of re-use, composition, and deployment

Example Plug-In Capabilities
- Translate documents
- Detect entities and/or relations of interest (semantic content)
- Detect & track topics of discussion
- Classify documents and terms – build taxonomies and glossaries
- Produce summaries
- Access, map and deliver structured information from specific knowledge sources according to central ontologies
UIMA: Two for One

- UIMA specifies two independent architectures
  - The Application Architecture
    - Collection of interfaces for the application developer
    - Divided into run-time and development time components
    - Includes the external interface for the Text Analysis Engine
  - The Text Analysis Engine Architecture
    - Collection of interfaces for the analysis engine developer
    - Divided up according to different roles
      - Annotator Developer
      - Analysis Engine Assembler
      - Analysis Engine Deployer
    - Exists independently of the application architecture
      - TAE may be built and embedded on other frameworks
      - UIMA frameworks may be implemented with TAEs that only conform to the application architecture’s specification for the TAE interface
The Common Analysis System (CAS)

Influenced by tagging and infrastructure work
Enables sharing analysis between components

A Container Class
- Original Artifact (e.g., document)
- Rich Meta-Data
  - Object-Based Representation
  - Type system supporting inheritance
- Stand-off annotations linking meta-data to elements of document

Implementations (C and Java)
- Highly-Efficient Access
- XML and Binary Serialization
- Efficient language interoperability
Example

George Bush, who was slipping in New Hampshire even before his third-place Iowa finish, lost more ground in polls this week. Democratic third-place finisher Michael Dukakis also lost support, but not as much. Iowa, meanwhile, has boosted the candidacies of Rep. Richard Gephardt of Missouri and Sen. Bob Dole of Kansas, the Democratic and Republican winners, and has added Pat Robertson, Iowa’s surprise second-place Republican finisher, to the polls indicate. As recently as two weeks ago, Bush commanded the New Hampshire GOP field. A CBS News-New York Times poll at the end of January had him 22 percentage points over Dole, the same place he’d held in polls since November and earlier. But Bush is still ahead, and when an ABC News-Washington Post poll found Bush’s lead sharply diminished, to 7 percentage points. After Iowa’s vote Monday, ABC found the spread down to 4 percentage points Bush 33, Dole 29. In a poll with an error margin of 6 percentage points, that amounted to a dead heat. Another survey, done for The Boston Globe this week by pollster Gary Orren, had essentially the same result. Bush 29, Dole 27. CBS on Thursday had it as Bush 35, Dole 27, still a big drop for the vice president. "Dole got a very big kick out of Iowa, more than that, there is some reluctance in the support for Bush," Orren said Thursday. "He’s shown vulnerability, and that’s sort of arousing doubt people have about him." "The unanswered question is how far Bush will fall," Richard Morin, polling director for The Washington Post. "The expectation is that he will continue to drop. That’s been the clear direction." If voters were leaving Bush before Iowa, it was not clear where they were going, Morin said. This week the chief gainers turned out to be Dole and Robertson, whose support was up to 10 percent in the ABC and CBS polls, from 6 percent last week and 4 percent two weeks ago. Rep. Jack Kemp of New York held steady at 13 percent in the ABC poll, and fell from 16 percent to 12 percent in the CBS poll. Analysts said he now may be challenged by Robertson for third place in New Hampshire. "Kemp was coming last week.

Legend

☑ Person ☐ Place ☐ Organization ☐ Cardinal ☐ Money ☐ Unknown Term
☐ Unknown Name ☐ Unknown Word ☐ Noun Phrase ☐ Verb Group
☐ Prepositional Phrase ☐ Government Official Title

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Key point: The combination hypothesis: If intimately integrated, various KM technologies will provide higher quality results (accuracy, recall, etc.)
UIMA

- A very promising beginning
- To be part of IBM OmniFind Product
- Likelihood of value
  - Commercial
  - Scientific
- Possibly of great significance for w/w community
  - Fragmentation long been a problem
  - Perhaps, this can provide the architectural framework
- Will the combination hypothesis provide a path to breakthrough results in accuracy and recall ... and also conversation
Blue Gene
Blue Gene program

December 1999: IBM Research announced a 5 year, $100M US, effort to build a petaflop/s scale supercomputer

Goals:
Advance the state of the art of scientific simulation.
Advance the state of the art in computer design and software for extremely large scale systems.

November 2002: Announced planned acquisition of a BG/L machine by LLNL as part of the ASCI Purple contract.

June 2003: First chips completed

November 2003: BG/L Half rack prototype (512 nodes) ranked #73 on 22nd Top500 List announced at SC2003 (1.435 TFlop/s).
32 node system folding proteins live on the demo floor at SC2003

Summer, 2004: Two Blue Gene machines make Top10 List
Dual Node Compute Card

Heatsinks designed for 15W (measuring ~13W @1.6V)

Metral 4000 connector

54 mm (2.125”)

206 mm (8.125”) wide, 14 layers

9 x 256Mb DRAM; 16B interface

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Midplane torus, tree, barrier, clock, Ethernet service port connects

16 compute cards

2 optional IO cards

Gb Ethernet connectors through tailstock

Latching and retention

DC-DC converters

Ethernet-JTAG FPGA
BlueGene/L Interconnection Nets

3 Dimensional Torus
- Interconnects all compute nodes (65,536)
- Virtual cut-through hardware routing
- 2.1 GB/s per node
- Communications backbone for computations
- 350/700 GB/s bisection bandwidth

Global Tree
- One-to-all broadcast functionality
- Reduction operations functionality
- 2.8 Gb/s of bandwidth per link
- Latency of tree traversal in the order of 5 µs
- Interconnects all compute & I/O nodes

Ethernet
- Incorporated into every node ASIC
- Active in the I/O nodes (1:64)
- All external comm. (file I/O, control, user interaction, etc.)
BG/L – Familiar software

- Fortran, C, C++ with MPI
  - Full language support
  - Automatic SIMD FPU exploitation

- Linux development environment
  - Cross-compilers and other cross-tools execute on Linux front-end nodes
  - Users interact with system from front-end nodes

- Tools – support for debuggers, hardware performance monitors, trace based visualization

- POSIX system calls – compute processes “feel like” they are executing on a Linux environment (restrictions)
BlueGene/L Hardware

- BG/L Architecture
- CPU
- Packaging, cooling
- Networks
- Performance
- Reliability/Availability
Design for Reliability & Availability

- Philosophy
  - Make system design choices to improve the reliability of the most failure-prone units

- Result
  - Total predicted FRU fails in 10 days without redundancy: 5.3
  - Total predicted FRU fails in 10 days with redundancy: 0.63
Hardware Summary

- Embedded technology promises to be an efficient path toward building massively parallel computers optimized at the system level.

- Cost/performance is ~20-50x better than standard methods to get to TFlops.

- Low Power is critical to achieving a dense, inexpensive packaging solution.

- Blue Gene/L will have a scientific reach far beyond existing limits for a large class of important scientific problems.

- Blue Gene/L will give insight into possible future product directions.

- Blue Gene/L hardware will be quite flexible. A mature, sophisticated software environment needs to be developed to really determine the reach (both scientific and commercial) of this architecture.
Software Design Summary

Familiar software development environment
- Fortran, C, C++ with MPI
  - Full language support
  - Automatic SIMD FPU exploitation
- Linux development environment
  - User interacts with system through FE nodes running Linux – compilation, job submission, debugging
  - Compute Node Kernel provides look and feel of a Linux environment – POSIX system calls (with restrictions)
- Tools – support for debuggers, hardware performance monitors, trace based visualization
- Research on higher level programming models

Scalability to $O(100,000)$ processors
**LINPACK summary**

- **Single-node** – 77% of peak
- **512-node** – 70% of peak
  - 1435 GFlop/s
  - #73 on Nov 2003 TOP500 list
- Has been a great test case/driver for the hardware and system software
- Two BlueGenes are now 2 of top-10 supercomputers on LINPACK!!!
A few conclusions

- We have developed a BG/L system software stack with Linux-like personality for user applications
  - Custom solution (CNK) on compute nodes for highest perf.
  - Linux solution on I/O nodes for flexibility and functionality
  - MPI is the default programming model, others are being investigated

- BG/L is testing software approaches to management/operation of very large scale machines
  - Hierarchical organization for management
  - “Flat” organization for programming
  - Mixed conventional/special-purpose operating systems

- Encouraging performance results – NAS Parallel Benchmarks, ASCI Purple Benchmarks, LINPACK

- Many challenges ahead
Autonomic Computing
**Autonomic Vision**

“Intelligent” open systems that:

- Manage complexity
- Know themselves
- Continuously tune themselves
- Adapt to unpredictable conditions
- Prevent and recover from failures
- Provide a safe environment

**Intelligent** systems provide:

- **Increase Responsiveness**
  - Adapt to dynamically changing environments

- **Operational Efficiency**
  - Tune resources and balance workloads to maximize use of IT resources

- **Secure Information and Resources**
  - Anticipate, detect, identify, and protect against attacks
  - Proactive security

- **Resiliency**
  - Act/react to prevent disruptions

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Autonomic Computing Research

Technologies for specific AC components

Generic technologies for AC components
- Autonomic Manager Toolset integrates many element-level technologies
  - Modeling, analysis, forecasting, optimization, planning, feedback control, etc.
- Policy Toolkit
- see [www.alphaworks.ibm.com](http://www.alphaworks.ibm.com) for some comp’s; open source anticipated

Generic technologies for AC systems
- Change management, Workload management, Dependency management, adaptive control, problem determination & remediation, ...
- These are basic technologies for achieving System Self-{Configuration, Healing, Optimization, and Protection}

AC System scenarios and prototypes
- Small- to medium-scale autonomic systems
- Demonstrate self-* arising from AC architecture + technology
- Identify gaps, necessary modifications
Adaptive Workload Surge Protection

- Forecaster
- Performance Modeler
- Statistics / Knowledge
- Controller
- Monitoring
- Configuration Management
- Driver (simulates Internet in/out)
- Surge Button
Learning Optimizer for DB2

1. Monitor
2. Analyze
3. Feedback
4. Exploit

SQL Compilation
 optimizer
 Best Plan
 Plan Execution
 Estimated Cardinalities
 Actual Cardinalities
 Statistics
 Adjustments
Autonomic Manager Toolkit

Facilitates autonomic mgr construction
In accordance w/ AC architecture

Aggregator for Generic AM technologies
Messaging (OGSA -> WebServices)
Policy tools
Monitoring technologies
AI tools for knowledge representation, reasoning
Math libraries for modeling, analysis, planning
Feedback control

V1.0 available as part of Emerging Technologies
Toolkit v 1.1 on IBM alphaWorks (www.alphaworks.ibm.com)

Considering open source

Major component for AC Toolbox

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Policy Management Overview

- **Goal**: Use higher level policies to drive configuration, operation and management of computer systems:
  - Systems configure themselves to meet policies.
  - Systems monitor policy compliance automatically.
  - Systems negotiate operational characteristics in accordance with policies.
A Few Personal Conclusions

- More opportunity in the field than ever before
- Many more topics than mentioned: e.g., security
- 10-years back, I thought much computer science was weak. I don't think so today
- There are many grand challenge problems that are today tractable
- Society wants and can benefit from our work
- Building blocks abound
- Great work can be done by university and industrial researchers - particularly as partners