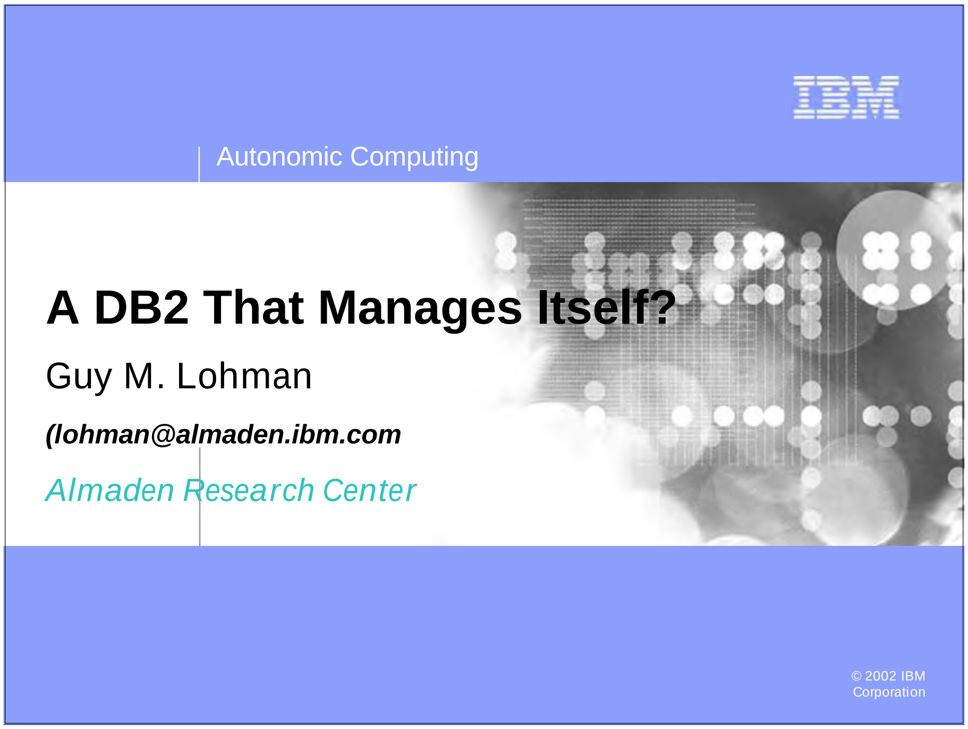

Autonomic Computing

A DB2 That Manages Itself?

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Almaden Research Center

The Idea

Wouldn't it be <u>great</u> if your
Database (and entire system!)
were as easy to maintain
and as self-controlled
as your
refrigerator?

Agenda

- Introduction & Motivation
- **DB2 Autonomic Computing Project**
- Existing DB2 Autonomic Features
  - Index Advisor
  - Configuration Advisor
  - Health Advisor
- New in “Stinger”
  - Design Advisor
  - Automated Statistics Collection
- Ad. Tech. & Research Projects
  - Progressive Optimization
- Conclusions

DB2 Autonomic Computing

✓ **Goal** -- Make DB2 Autonomic

★ **The Project**:

- ✓ Multi-Platform (Linux, Unix, Windows, mainframe)
- ✓ Multi-Division (Research, Development)
- ✓ Multi-Site (Toronto, Almaden, Silicon Valley, Watson)
- ✓ Part of IBM’s company-wide “Autonomic Computing” initiative

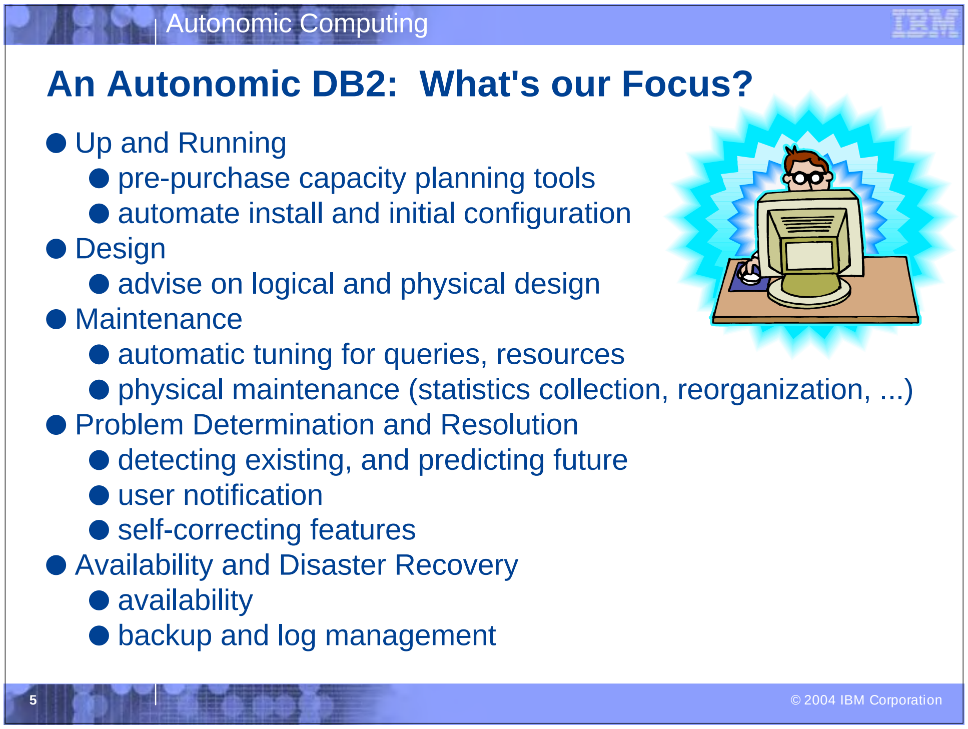
★ **Leaders**:

- ✓ Toronto Lab: **Sam Lightstone**, Randy Horman, Mark Wilding
- ✓ SVL: Jim Teng (z/OS), Bryan Smith (tools)
- ✓ Research: Guy Lohman (ARC), Joe Hellerstein (Watson)

★ **History**:

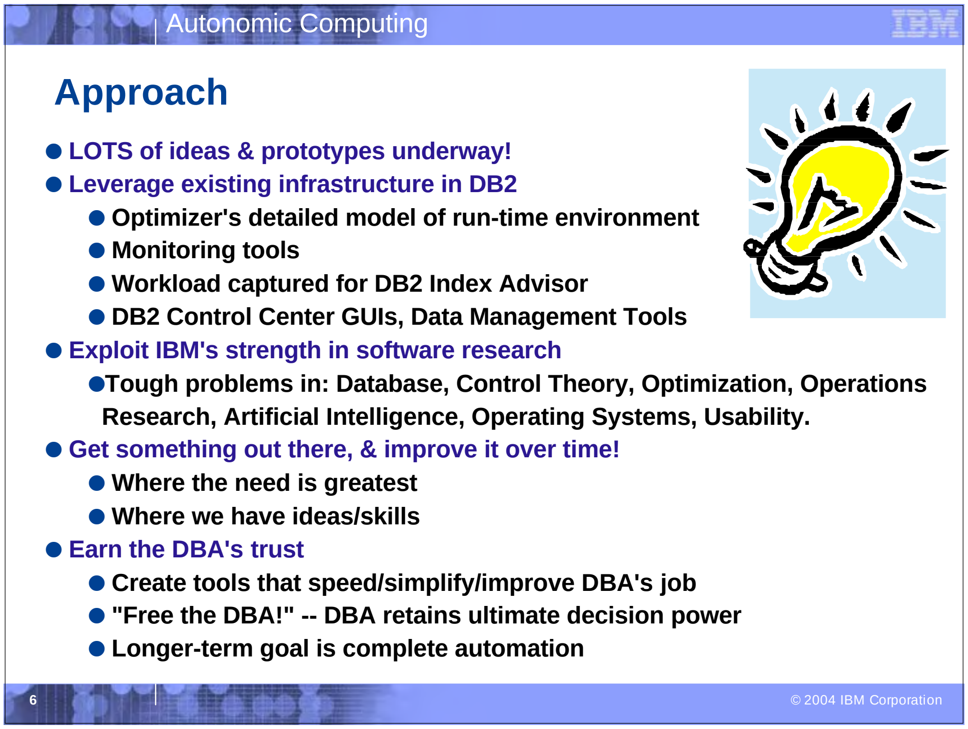
- ✓ Index Advisor prototyped in 1998
- ✓ Project formed in early 2000
  - ☞ **Previously called Self-Managing And Resource Tuning (SMART)**
- ✓ IBM-wide Autonomic Computing initiative
- ✓ Evolutionary: Multi-Release Rollout

☞ **Refn**: *SMART: Making DB2 (More) Autonomic*, **VLDB 2002**



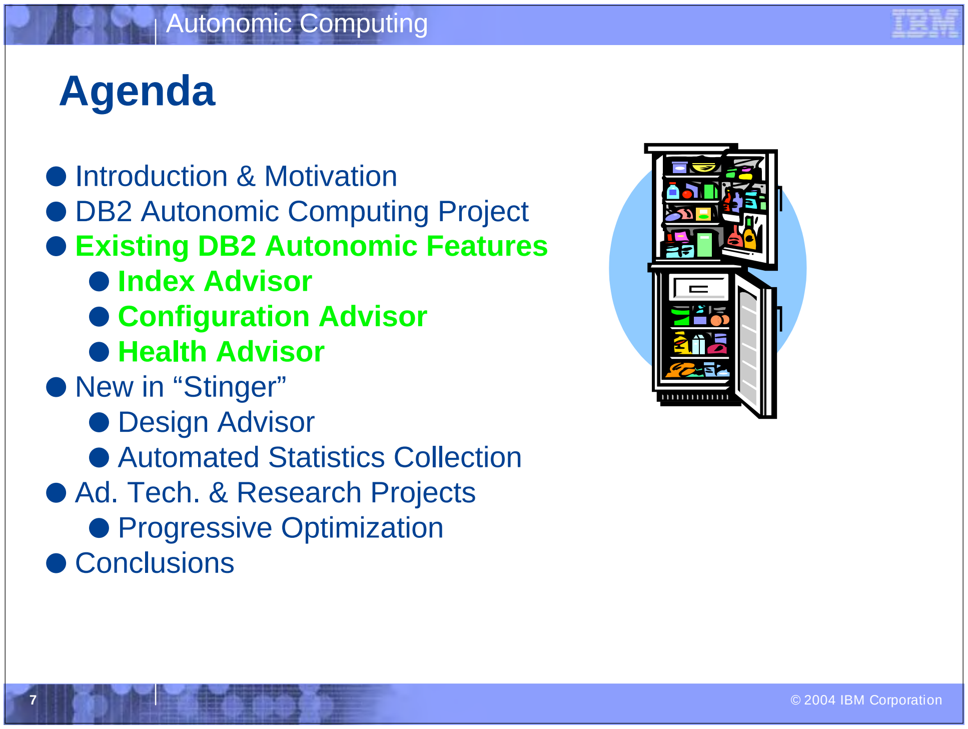
An Autonomic DB2: What's our Focus?

- Up and Running
  - pre-purchase capacity planning tools
  - automate install and initial configuration
- Design
  - advise on logical and physical design
- Maintenance
  - automatic tuning for queries, resources
  - physical maintenance (statistics collection, reorganization, ...)
- Problem Determination and Resolution
  - detecting existing, and predicting future
  - user notification
  - self-correcting features
- Availability and Disaster Recovery
  - availability
  - backup and log management



Approach

- **LOTS of ideas & prototypes underway!**
- **Leverage existing infrastructure in DB2**
  - **Optimizer's detailed model of run-time environment**
  - **Monitoring tools**
  - **Workload captured for DB2 Index Advisor**
  - **DB2 Control Center GUIs, Data Management Tools**
- **Exploit IBM's strength in software research**
  - **Tough problems in: Database, Control Theory, Optimization, Operations Research, Artificial Intelligence, Operating Systems, Usability.**
- **Get something out there, & improve it over time!**
  - **Where the need is greatest**
  - **Where we have ideas/skills**
- **Earn the DBA's trust**
  - **Create tools that speed/simplify/improve DBA's job**
  - **"Free the DBA!" -- DBA retains ultimate decision power**
  - **Longer-term goal is complete automation**



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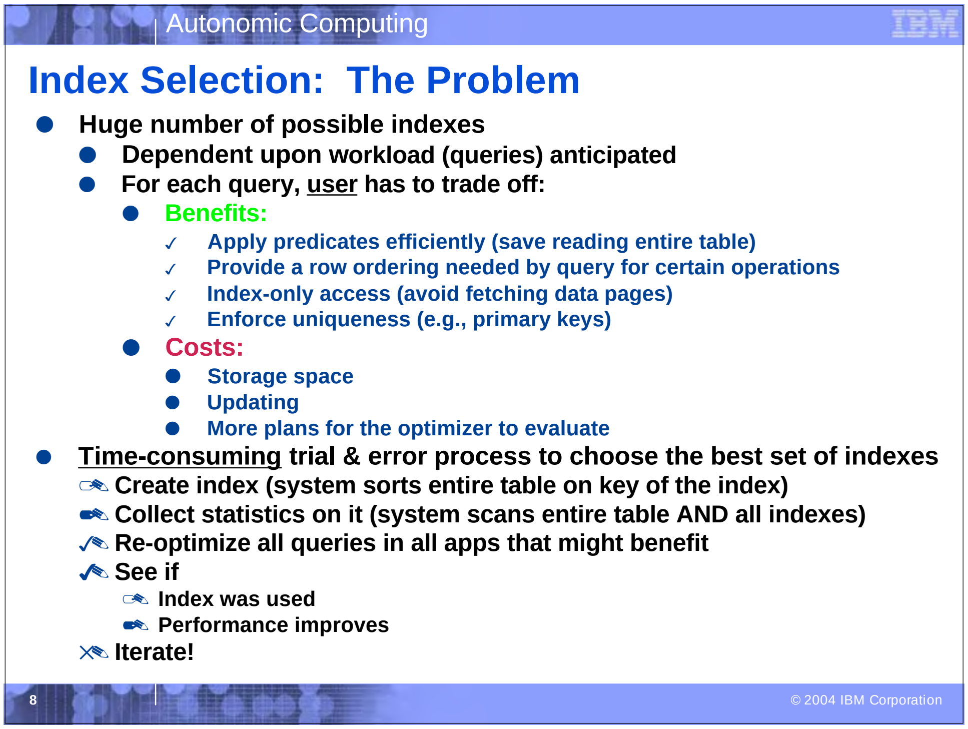
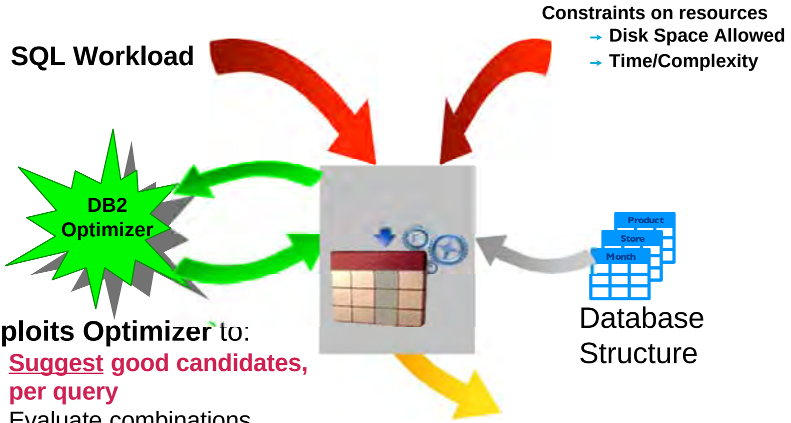


Index Selection: The Problem

- **Huge number of possible indexes**
  - **Dependent upon workload (queries) anticipated**
  - **For each query, user has to trade off:**
    - **Benefits:**
      - ✓ **Apply predicates efficiently (save reading entire table)**
      - ✓ **Provide a row ordering needed by query for certain operations**
      - ✓ **Index-only access (avoid fetching data pages)**
      - ✓ **Enforce uniqueness (e.g., primary keys)**
    - **Costs:**
      - **Storage space**
      - **Updating**
      - **More plans for the optimizer to evaluate**
- **Time-consuming trial & error process to choose the best set of indexes**
  - ☞ **Create index (system sorts entire table on key of the index)**
  - ☛ **Collect statistics on it (system scans entire table AND all indexes)**
  - ✓ **Re-optimize all queries in all apps that might benefit**
  - ✔ **See if**
    - ☞ **Index was used**
    - ☛ **Performance improves**
  - ✗ **Iterate!**

Solution(1): DB2 Index Advisor (V6, 1999)



Exploits Optimizer to:

- ★ **<u>Suggest</u> good candidates, per query**
- ★ <u>Evaluate</u> combinations, for entire workload

Indexes Designed by DB2 for <u>Your</u> Environment & Workload

Index Advisor (DB2 V6) – The Math

- Variant of well-known "Knapsack" Problem
- Greedy "bang-for-buck" solution is optimal, when integrality of objects (indexes) is relaxed

- For each query Q:
  - ➢ Baseline: Explain each query w/ existing indexes, to get cost E(Q)
  - ➢ Unconstrained: Explain each query in RECOMMEND INDEXES mode, to get cost U(Q)
  - ➢ Improvement ("benefit") B(Q) = E(Q) - U(Q)
- For each index I used by one or more queries:
  - ➢If query Q used index I, assign "benefit" B(Q) to index I: B(I) = B(I) + B(Q)
  - ➢Assign "cost" C(I) = size of index in bytes
  - ➢Order indexes by decreasing B(I) / C(I) ("bang for buck")
  - ➢Cut off where cumulative C(I) exceeds disk budget
- Iterative improvement: exchange handfuls of "winners" with "losers“

● **REFN: “DB2 Advisor: An Optimizer Smart Enough to Recommend its Own Indexes", ICDE 2000 (San Diego), Valentin, Zuliani, Zilio, Lohman, et al.**

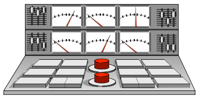
Configuration Parameters

- **The Problem:**
  - Almost 150 configuration parameters in DB2 UDB
  - Users didn’t know:

    How to choose the right values

    Possible interactions between them
  - Had to stop and restart DB2 to have them go into effect

    Bad for availability, too!



- **Solution(1):**
  - Make many configuration parameters dynamic!
  - No need to stop and restart DB2 to change them
  - Not easy to implement, e.g. shrinking buffer pool
  - Shipped in DB2 UDB V8.1 (2002)
  - Prerequisite to automatically tuning them

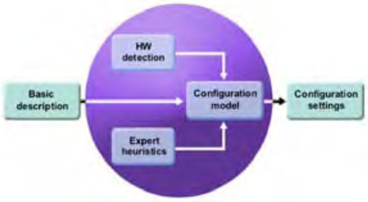
Solution(2): Configuration Advisor (V8.1, 2002)

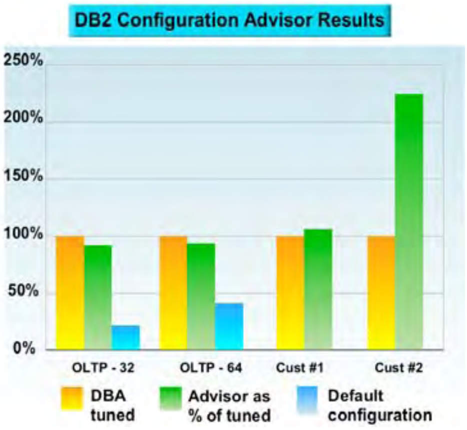
- **What is it?**
  - Sets ~36 configuration parameters key to performance, including:
    - Memory heaps (buffer pool, sort heap, statement cache)
    - Connections (max and average, remote/local)
  - Based upon answers to 7 high-level questions
  - Equations from performance experts relate parameters
- **Enhanced in V8.1:**
  - Available in V7 as "Performance Configuration Wizard“
  - More sophisticated model in V8.1
  - Easier to invoke via:
    - CREATE DATABASE command extension
    - AUTOCONFIGURE command
  - Better decisions for OLTP and DSS workloads
  - Surprising benchmark results
    (well-known, industry-standard OLTP workload)

Configuration Advisor: The Questions

- Percentage of Real Memory to dedicate to DBMS
- OLTP vs. Complex query vs. Mixed
- Length of Transaction (typical # of SQL queries per transaction)
- Relative priority of Recovery vs. Query speed
- Number of Local and Remote Connections
- Whether the database is populated or not
- Isolation Level

DB2 Configuration Advisor vs. Human Experts



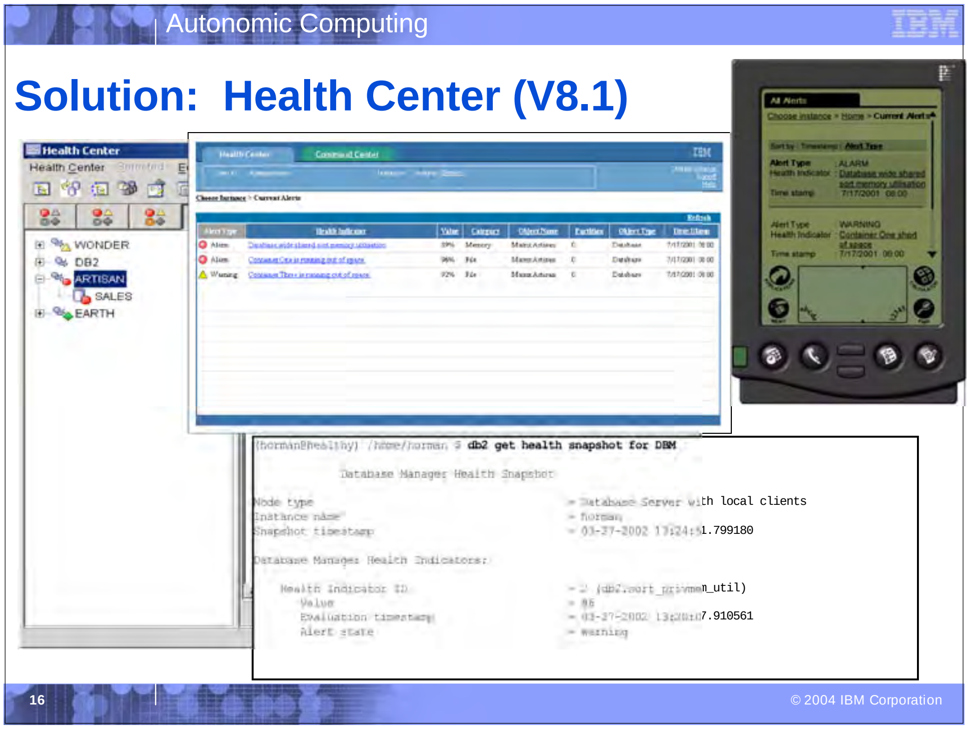


- ***Speeds deployment***
- ***Improves performance***
- ***Frees up resource***

Health Monitoring

- **The Problem:**
  - How do you know if DB2 is running okay, performing well?
  - What do you do if you <u>do</u> manage to figure out it's "unhealthy"?
  - Too difficult to determine what to monitor and when to monitor it
  - Need to set up monitors, notification & resolution mechanisms
- **The Solution: Health Center**
  - DB2 monitors its own health right out of the box
  - Notifies user upon encountering unhealthy conditions
  - Advises on severity of condition, and suggests resolutions
  - Initiates corrective action if required, requested
  - Easy installation: just provide an e-mail or pager address
  - User can modify thresholds for notification

Solution: Health Center (V8.1)



Choose Instance > Current Alerts

Alert Type	Health Indicator	Value	Category	Object Name	Partition	Object Type	Date/Time
Alarm	Database wide shared sort memory utilisation	89%	Memory	[illegible]	0	Database	7/17/2001 08:00
Alarm	Container One is running out of space	96%	File	[illegible]	0	Database	7/17/2001 08:00
Warning	Container Three is running out of space	92%	File	[illegible]	0	Database	7/17/2001 08:00

Choose instance > Home > Current Alerts

Sort by : Timestamp : Alert Type

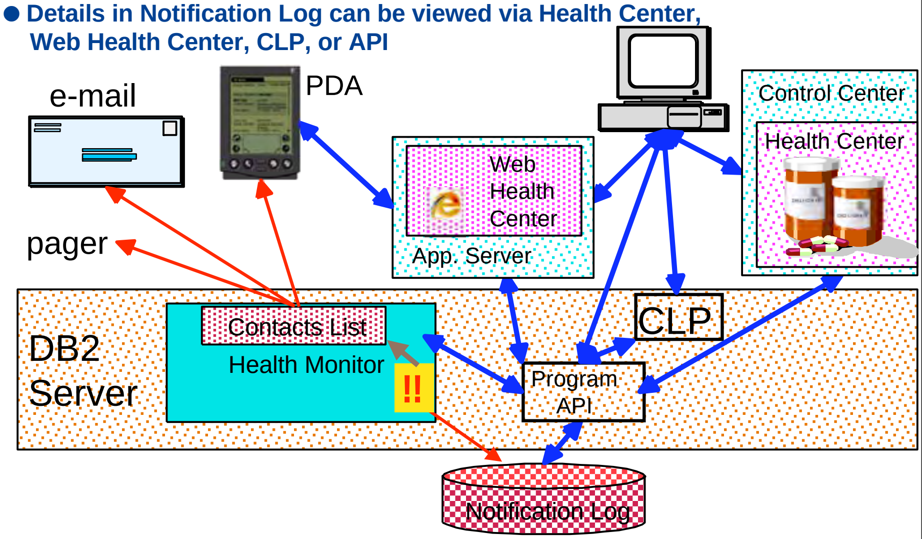
Alert Type : ALARM
Health Indicator : Database wide shared sort memory utilisation
Time stamp : 7/17/2001 08:00

Alert Type : WARNING
Health Indicator : Container One short of space
Time stamp : 7/17/2001 08:00

```
(norman@healthy) /home/norman $ db2 get health snapshot for DBM

            Database Manager Health Snapshot

Node type                                   = Database Server with local clients
Instance name                               = norman
Snapshot timestamp                          = 03-27-2002 13:24:51.799180

Database Manager Health Indicators:

    Health Indicator ID                     = 2 (db2.sort_privmem_util)
       Value                                = 86
       Evaluation timestamp                 = 03-27-2002 13:20:07.910561
       Alert state                          = Warning
```

Health Monitor and Health Center

- **Alerts sent by Health Monitor to Contacts on Contacts List**
- **Details in Notification Log can be viewed via Health Center, Web Health Center, CLP, or API**



Health Center: "Drilling Down"

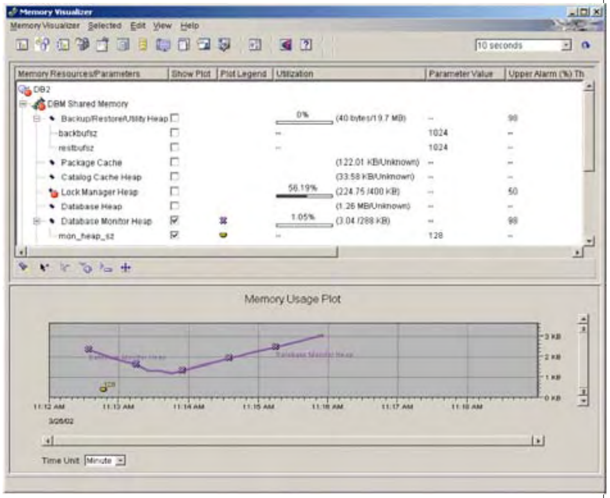
- If you need to do some digging/investigation before choosing an appropriate action, Health Center launches tools in context

e.g. **Use Memory Visualizer to consider "competitors" of a constrained resource**

Other investigative actions include:

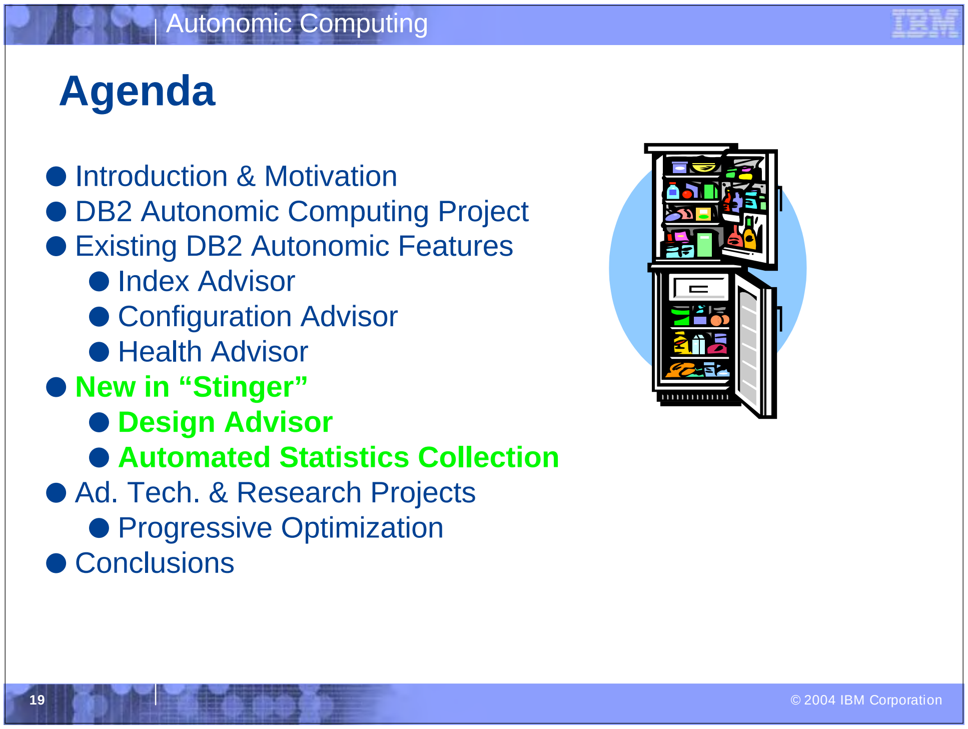
- **Storage Management**
- **Indoubt Transaction Manager**
- **Event Monitor**

NOTE: for many corrective actions, DB/DBM cfg parms can be dynamically updated!!!



Memory Resources/Parameters	Show Plot	Plot Legend	Utilization	Parameter Value	Upper Alarm (%) Th
DB2					
DBM Shared Memory					
Backup/Restore/Utility Heap	☐		0% (40 bytes/19.7 MB)	--	90
backbufsz	☐		--	1024	--
restbufsz	☐		--	1024	--
Package Cache	☐		(122.01 KB/Unknown)	--	--
Catalog Cache Heap	☐		(33.58 KB/Unknown)	--	--
Lock Manager Heap	☐		56.19% (224.75 /400 KB)	--	50
Database Heap	☐		(1.26 MB/Unknown)	--	--
Database Monitor Heap	☑		1.05% (3.04 /288 KB)	--	90
mon_heap_sz	☑		--	128	--

Time Unit: Minute



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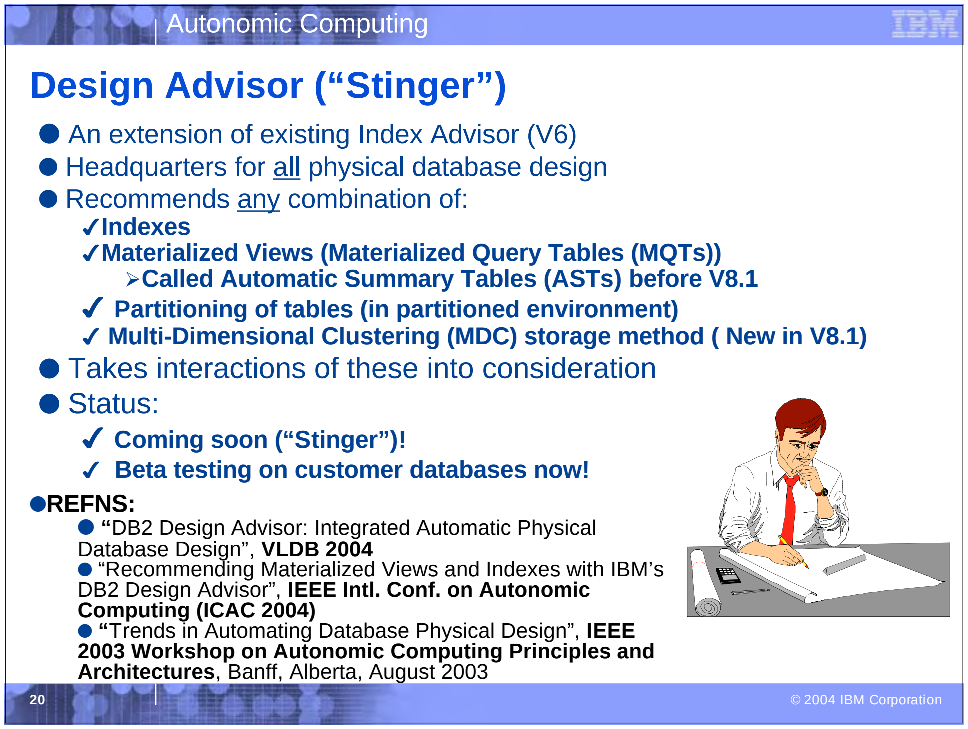
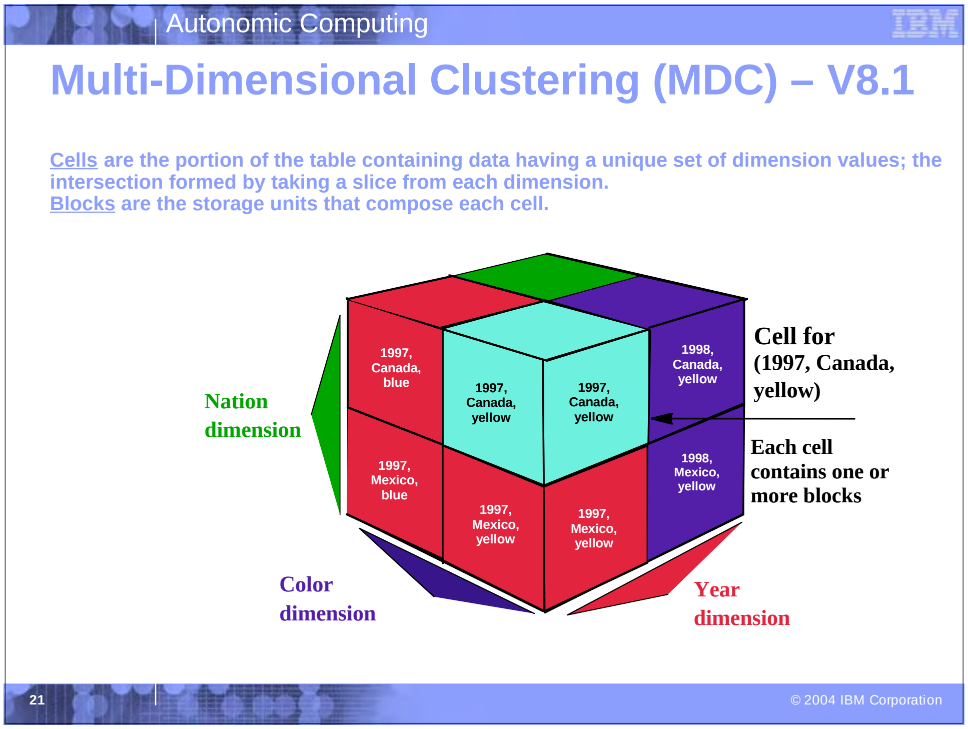


Design Advisor (“Stinger”)

- An extension of existing Index Advisor (V6)
- Headquarters for all physical database design
- Recommends any combination of:
  - ✓**Indexes**
  - ✓**Materialized Views (Materialized Query Tables (MQTs))**
    - ➢**Called Automatic Summary Tables (ASTs) before V8.1**
  - ✓ **Partitioning of tables (in partitioned environment)**
  - ✓ **Multi-Dimensional Clustering (MDC) storage method (New in V8.1)**
- Takes interactions of these into consideration
- Status:
  - ✓ **Coming soon (“Stinger”)!**
  - ✓ **Beta testing on customer databases now!**

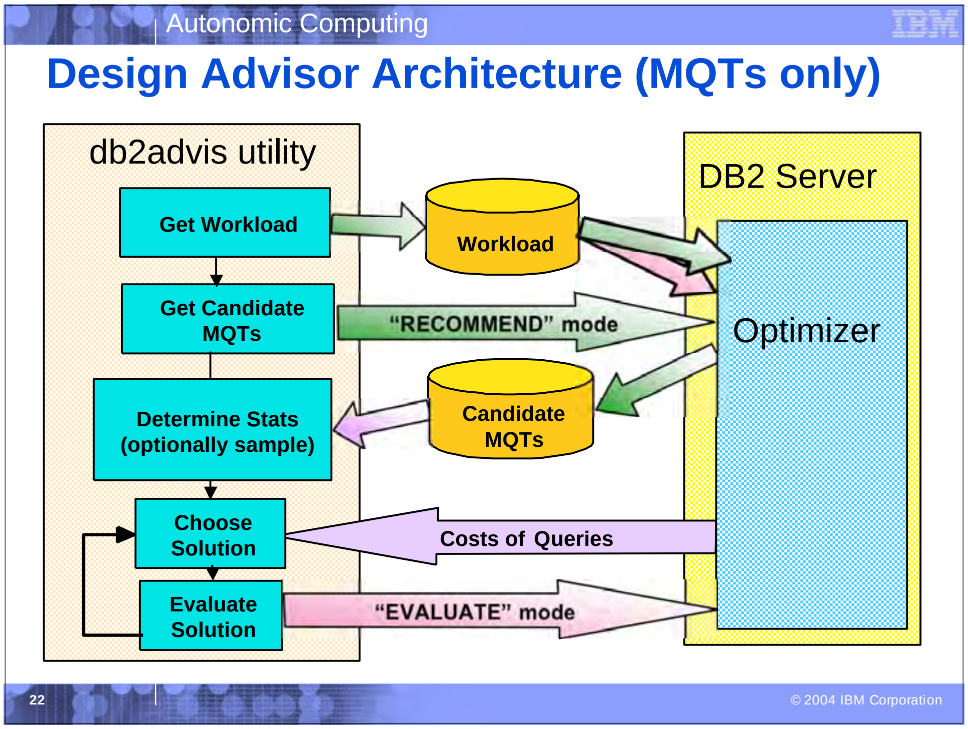
●**REFNS:**

- **“**DB2 Design Advisor: Integrated Automatic Physical Database Design”, **VLDB 2004**
- “Recommending Materialized Views and Indexes with IBM’s DB2 Design Advisor”, **IEEE Intl. Conf. on Autonomic Computing (ICAC 2004)**
- **“**Trends in Automating Database Physical Design”, **IEEE 2003 Workshop on Autonomic Computing Principles and Architectures**, Banff, Alberta, August 2003

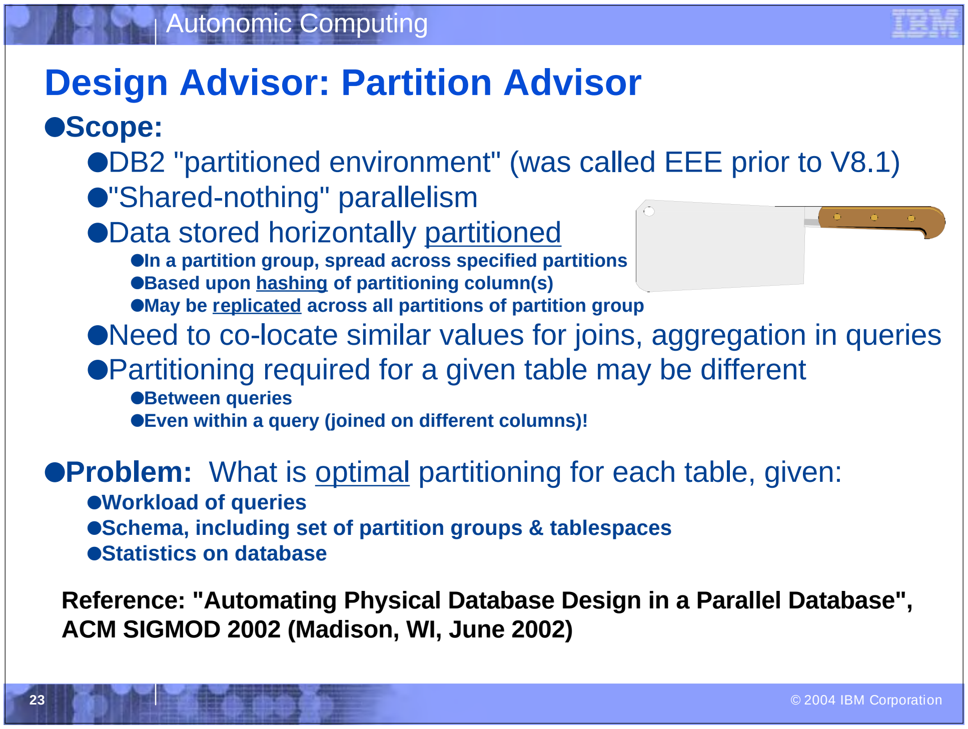


Multi-Dimensional Clustering (MDC) – V8.1

Cells are the portion of the table containing data having a unique set of dimension values; the intersection formed by taking a slice from each dimension.
Blocks are the storage units that compose each cell.



Design Advisor Architecture (MQTs only)

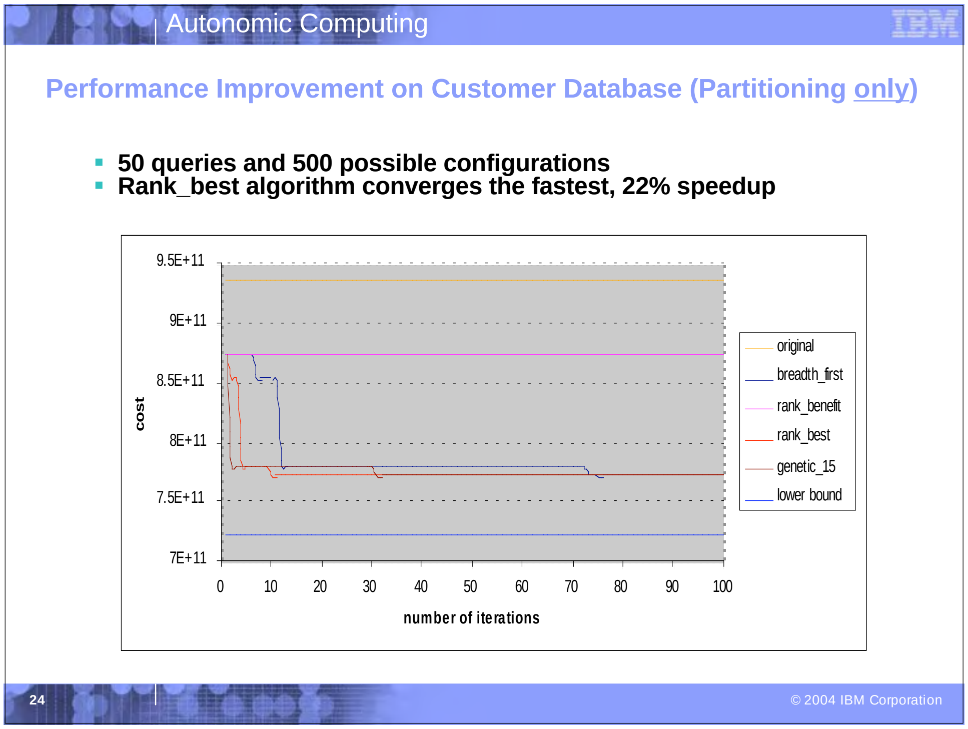


Design Advisor: Partition Advisor

- **Scope:**
  - DB2 "partitioned environment" (was called EEE prior to V8.1)
  - "Shared-nothing" parallelism
  - Data stored horizontally partitioned
    - **In a partition group, spread across specified partitions**
    - **Based upon hashing of partitioning column(s)**
    - **May be replicated across all partitions of partition group**
  - Need to co-locate similar values for joins, aggregation in queries
  - Partitioning required for a given table may be different
    - **Between queries**
    - **Even within a query (joined on different columns)!**

- **Problem:** What is optimal partitioning for each table, given:
  - **Workload of queries**
  - **Schema, including set of partition groups & tablespaces**
  - **Statistics on database**

Reference: "Automating Physical Database Design in a Parallel Database", ACM SIGMOD 2002 (Madison, WI, June 2002)



Performance Improvement on Customer Database (Partitioning only)

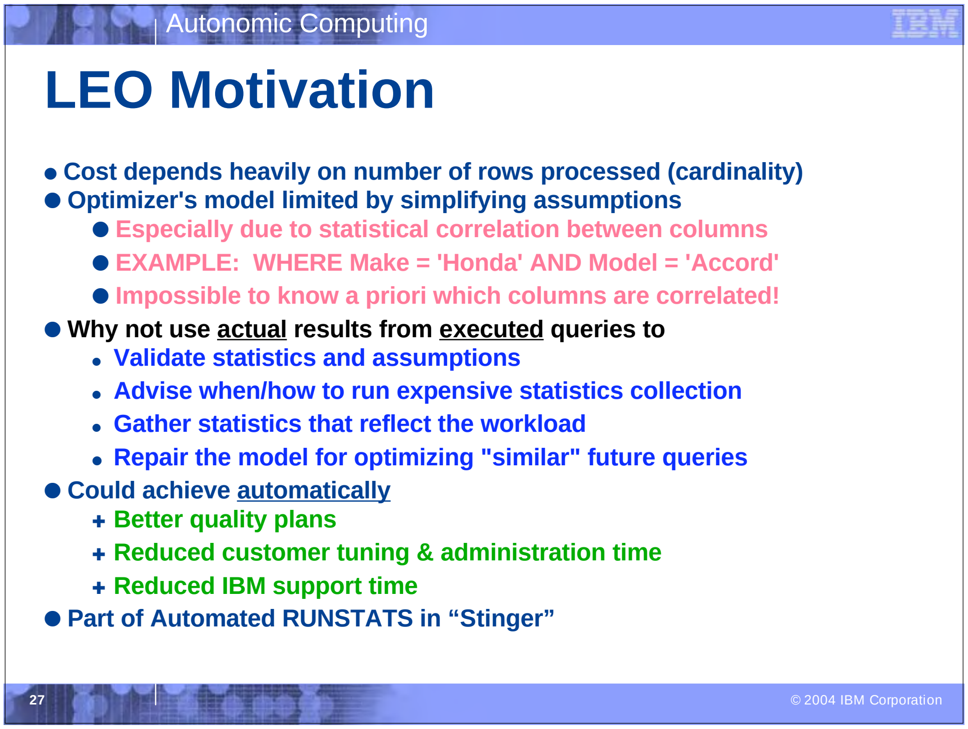
- **50 queries and 500 possible configurations**
- **Rank_best algorithm converges the fastest, 22% speedup**

Automating Statistics Collection:

- **Problem:**
  - Optimizer requires that statistics on database be
    - Up to date (after updates)
    - Complete (multi-column)
  - User must invoke RUNSTATS
- **Solution**: Automate RUNSTATS
  - ***Invocation*** scheduled and prioritized
  - ***Run silently*** as a background daemon
    - Throttled based upon workload
  - **LEO** the **LE**arning **O**ptimizer determines which ***statistics needed***
    - Based upon learning from past queries
    - Groups of columns
      - Enables correlation detection
    - Communicated to RUNSTATS via statistical "profiles"
- Shipping in DB2 "Stinger"
- **Refn**: "Automated Statistics Collection in DB2 Stinger", **VLDB 2004**

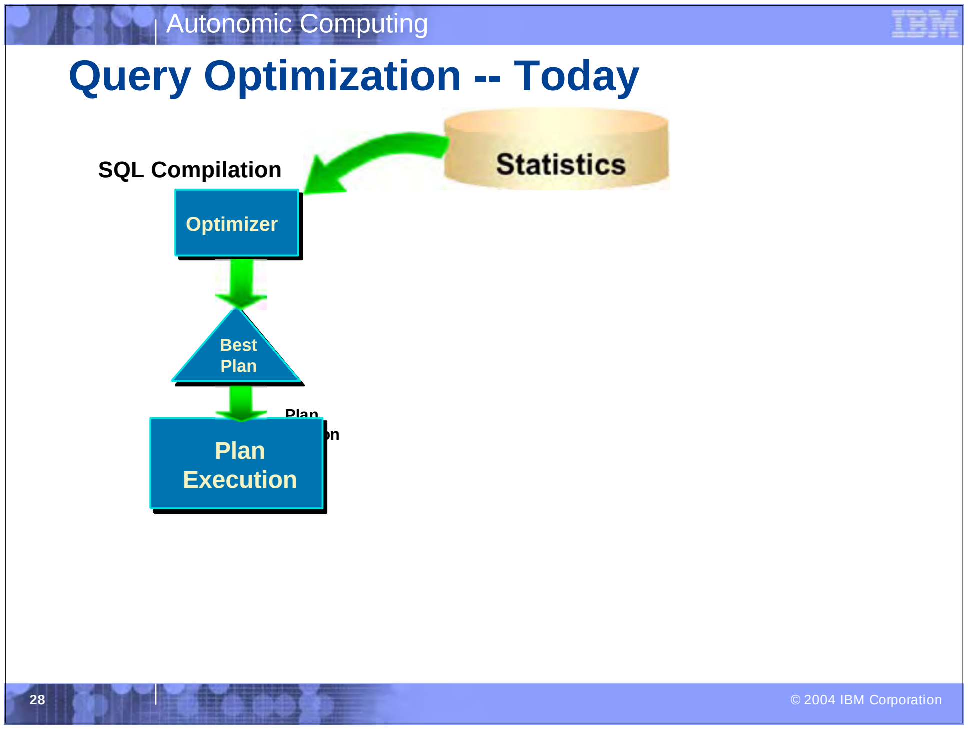
Automating Statistics Collection:
LEO the LEarning Optimizer Determines Statistics Profiles

Refn: "LEO -- DB2's LEarning Optimizer", Intl. Conf. on
Very Large Data Bases 2001 (Rome, Sept. 2001)



LEO Motivation

- Cost depends heavily on number of rows processed (cardinality)
- Optimizer's model limited by simplifying assumptions
  - Especially due to statistical correlation between columns
  - EXAMPLE: WHERE Make = 'Honda' AND Model = 'Accord'
  - Impossible to know a priori which columns are correlated!
- Why not use actual results from executed queries to
  - Validate statistics and assumptions
  - Advise when/how to run expensive statistics collection
  - Gather statistics that reflect the workload
  - Repair the model for optimizing "similar" future queries
- Could achieve automatically
  - + Better quality plans
  - + Reduced customer tuning & administration time
  - + Reduced IBM support time
- Part of Automated RUNSTATS in “Stinger”



Query Optimization -- Today

SQL Compilation

Statistics

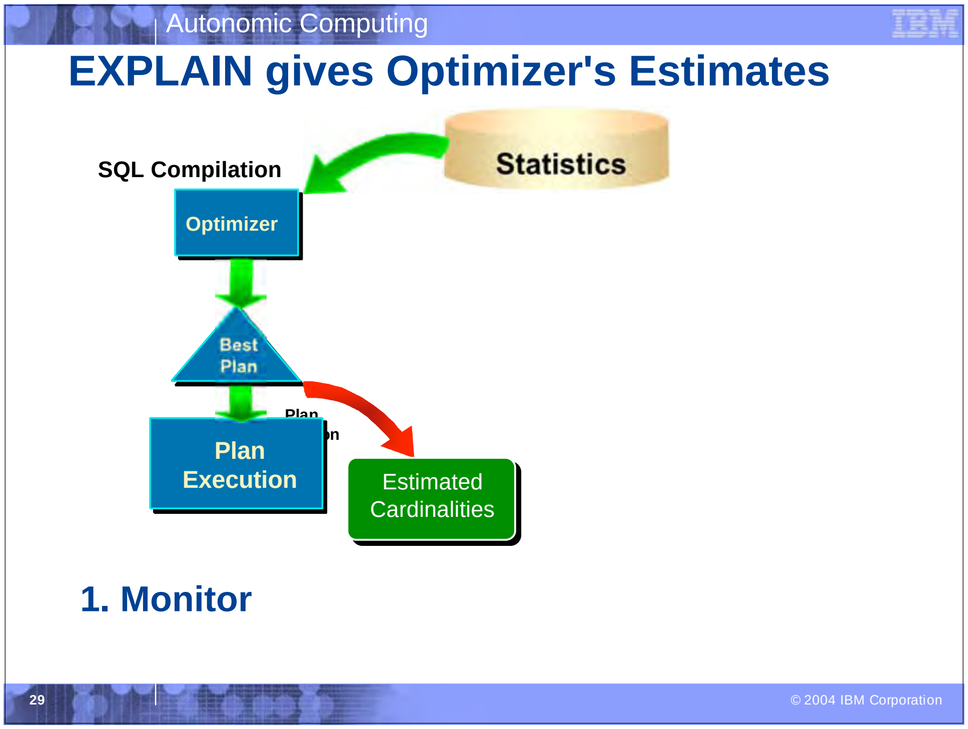
Optimizer

Best Plan

Plan

n

Plan Execution



Autonomic Computing

EXPLAIN gives Optimizer's Estimates

SQL Compilation

Statistics

Optimizer

Best Plan

Plan

n

Plan Execution

Estimated Cardinalities

1. Monitor

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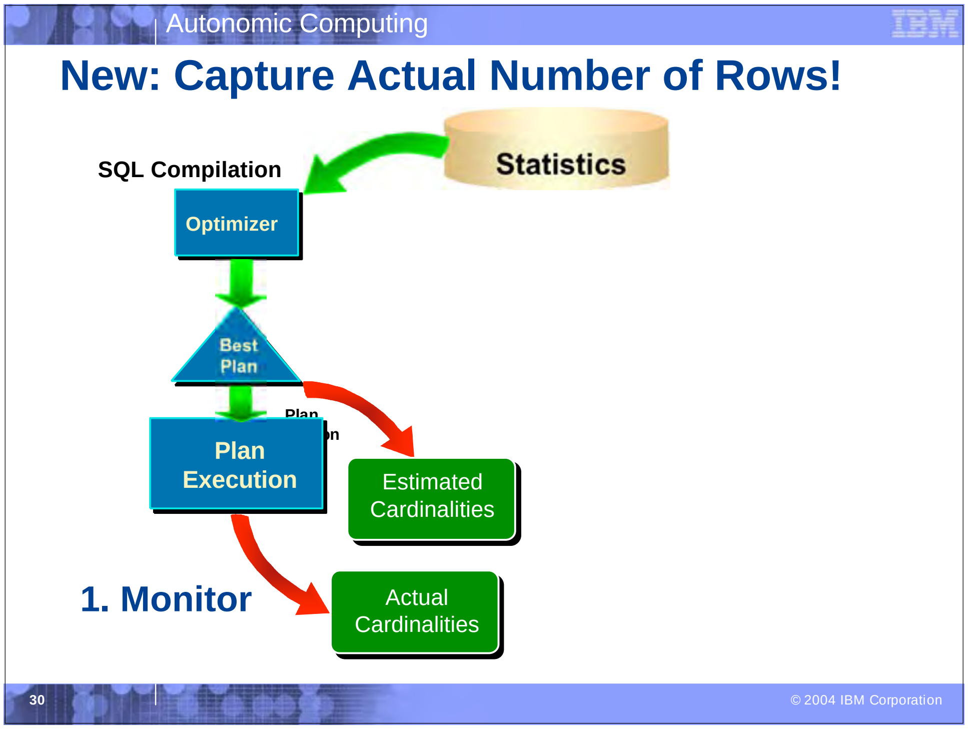

Autonomic Computing

New: Capture Actual Number of Rows!

SQL Compilation

Statistics

Optimizer

Best Plan

Plan

n

Plan Execution

Estimated Cardinalities

1. Monitor

Actual Cardinalities

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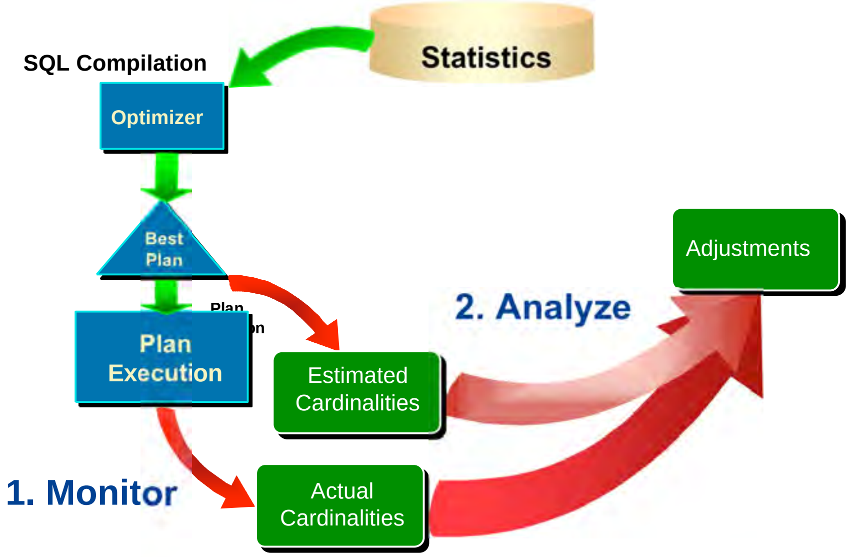
Autonomic Computing

Figure Out Where the Differences Are


SQL Compilation

Statistics

Optimizer

Best Plan

Plan

n

Plan Execution

Adjustments

2. Analyze

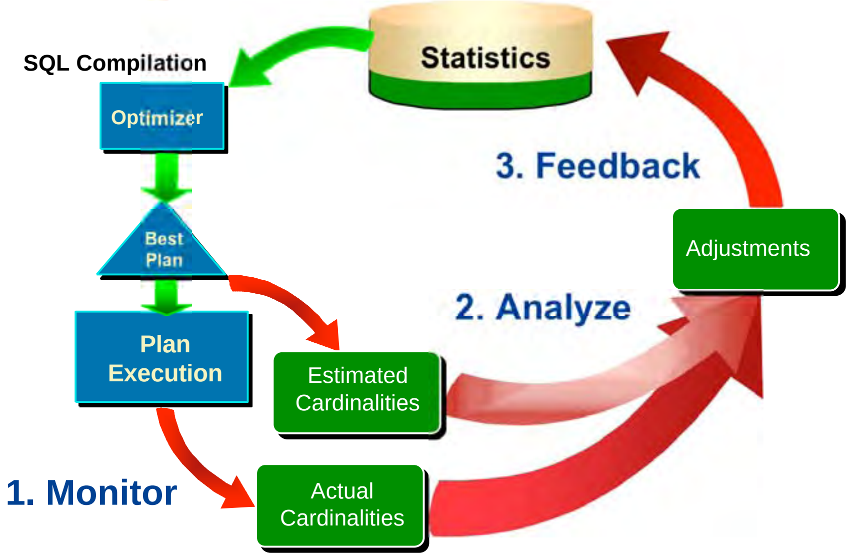
Estimated Cardinalities

1. Monitor

Actual Cardinalities

Autonomic Computing

Augment Statistics with Adjustments


SQL Compilation

Statistics

Optimizer

3. Feedback

Best Plan

Adjustments

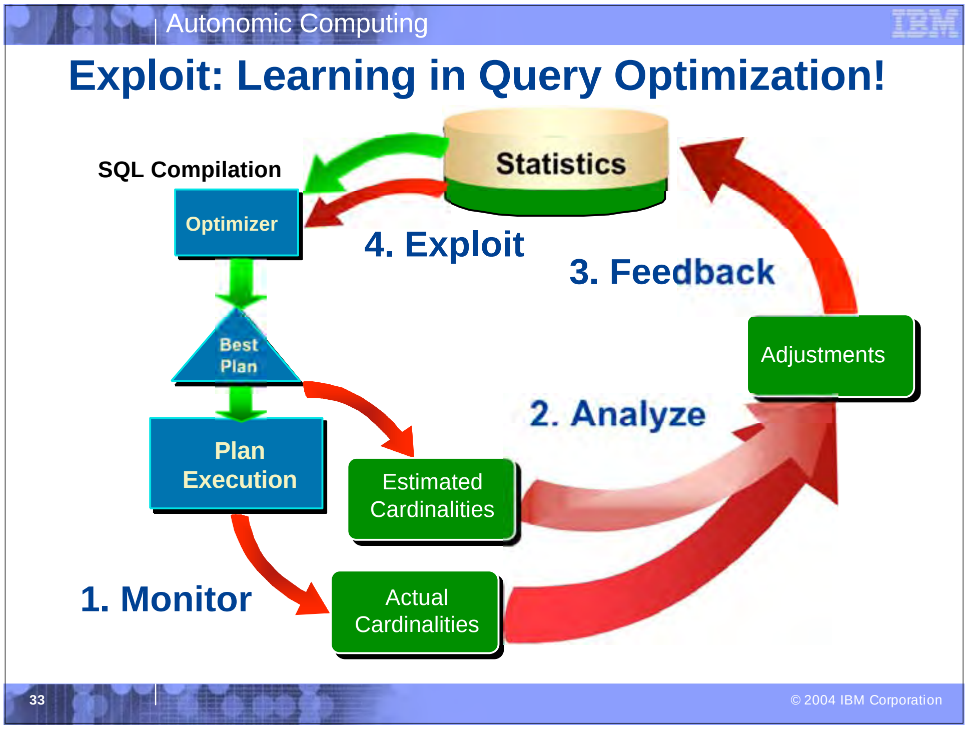
2. Analyze

Plan Execution

Estimated Cardinalities

1. Monitor

Actual Cardinalities



Exploit: Learning in Query Optimization!

SQL Compilation

Optimizer

Best Plan

Plan Execution

Statistics

4. Exploit

3. Feedback

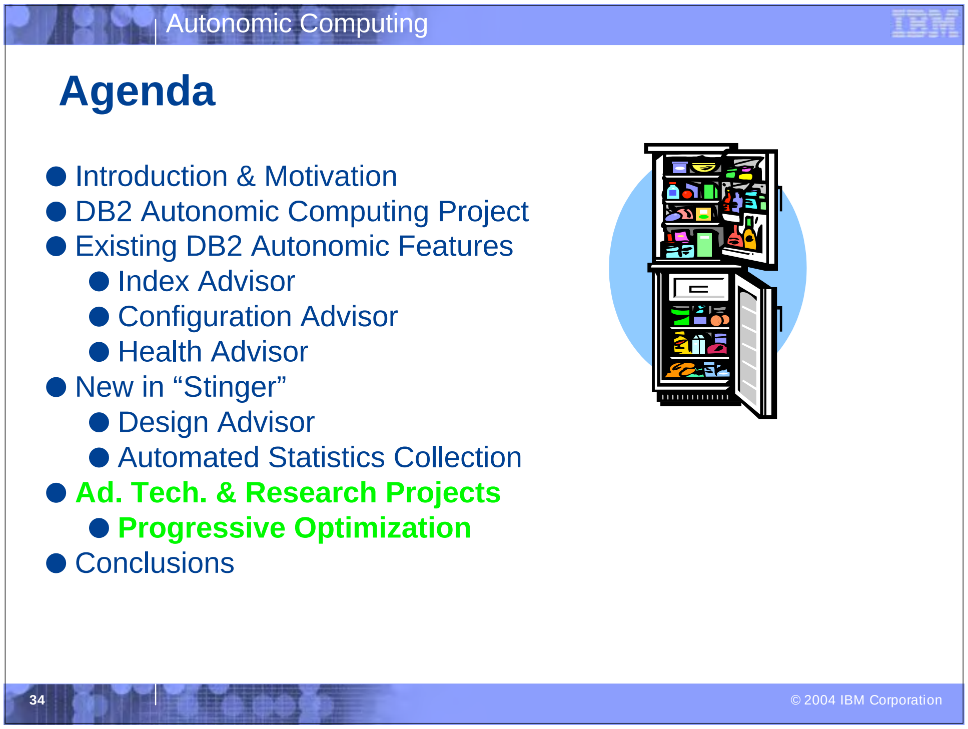
Adjustments

2. Analyze

Estimated Cardinalities

Actual Cardinalities

1. Monitor



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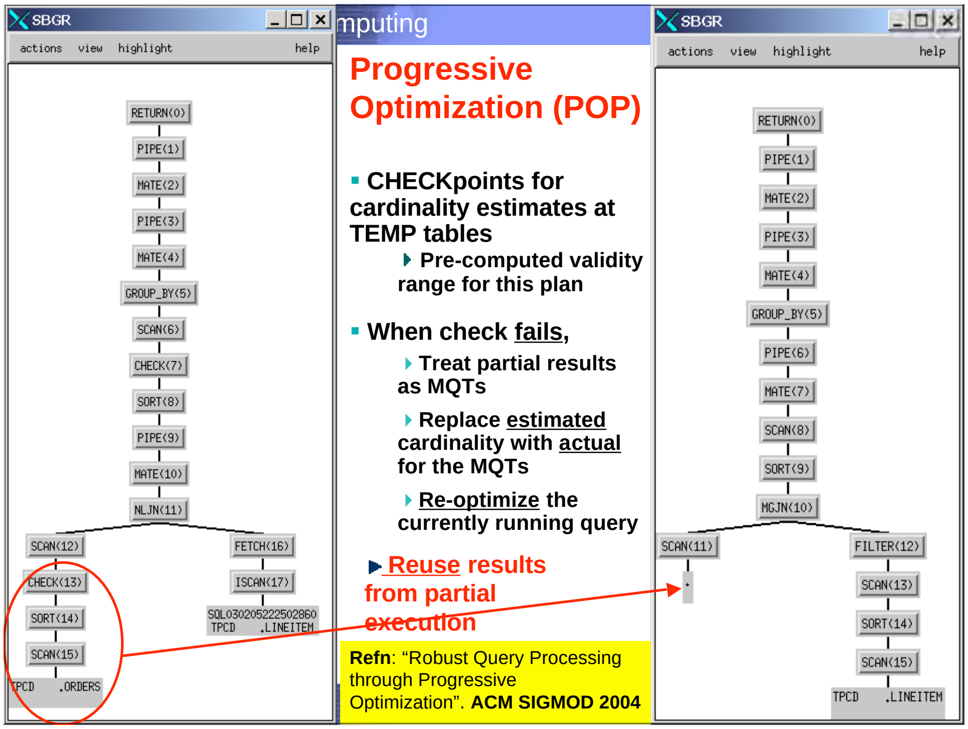


Progressive Optimization (POP)

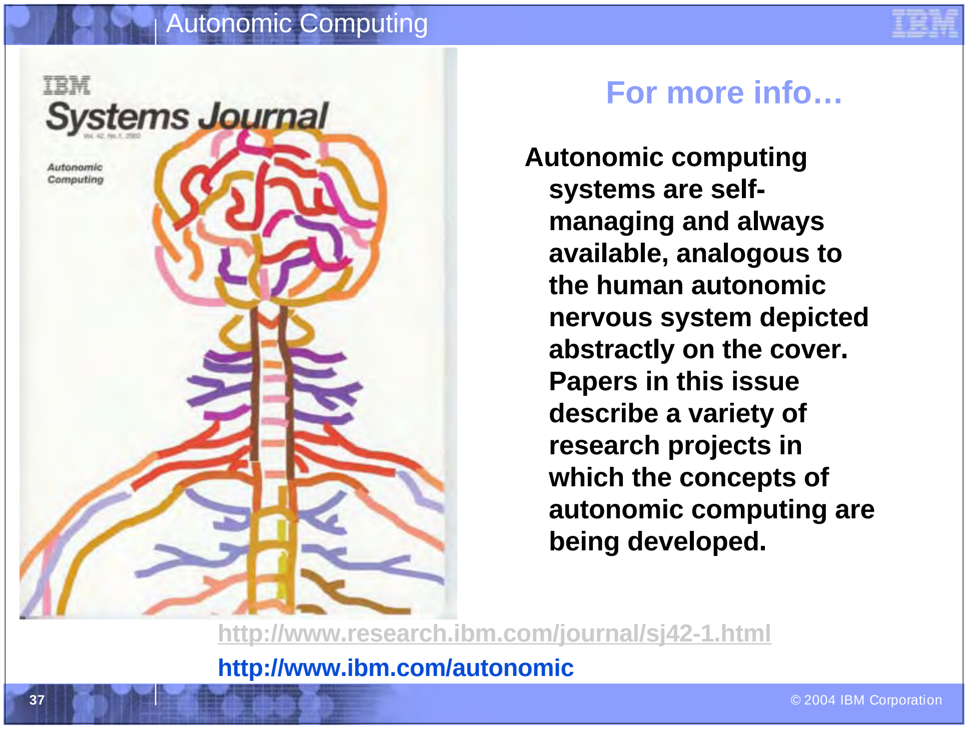
- CHECKpoints for cardinality estimates at TEMP tables
  - Pre-computed validity range for this plan
- When check fails,
  - Treat partial results as MQTs
  - Replace estimated cardinality with actual for the MQTs
  - Re-optimize the currently running query

- Reuse results from partial execution

Refn: "Robust Query Processing through Progressive Optimization". **ACM SIGMOD 2004**

Conclusions & Future Directions

- Autonomic features of DB2:
  - Key to lowering Total Cost of Ownership
  - A major DB2 differentiator
  - Now in DB2 are the "tip of the iceberg"!
  - Many more on the way in technology stream from
    - Development
    - Research
    - Universities
  - Rollout prioritized by Customers ("Free the DBAs!")
  - Beginning to integrate IBM components autonomically
  - Ultimate goal is complete automation!



Autonomic Computing

IBM
Systems Journal
Autonomic Computing

For more info…

Autonomic computing systems are self-managing and always available, analogous to the human autonomic nervous system depicted abstractly on the cover. Papers in this issue describe a variety of research projects in which the concepts of autonomic computing are being developed.

http://www.research.ibm.com/journal/sj42-1.html

http://www.ibm.com/autonomic

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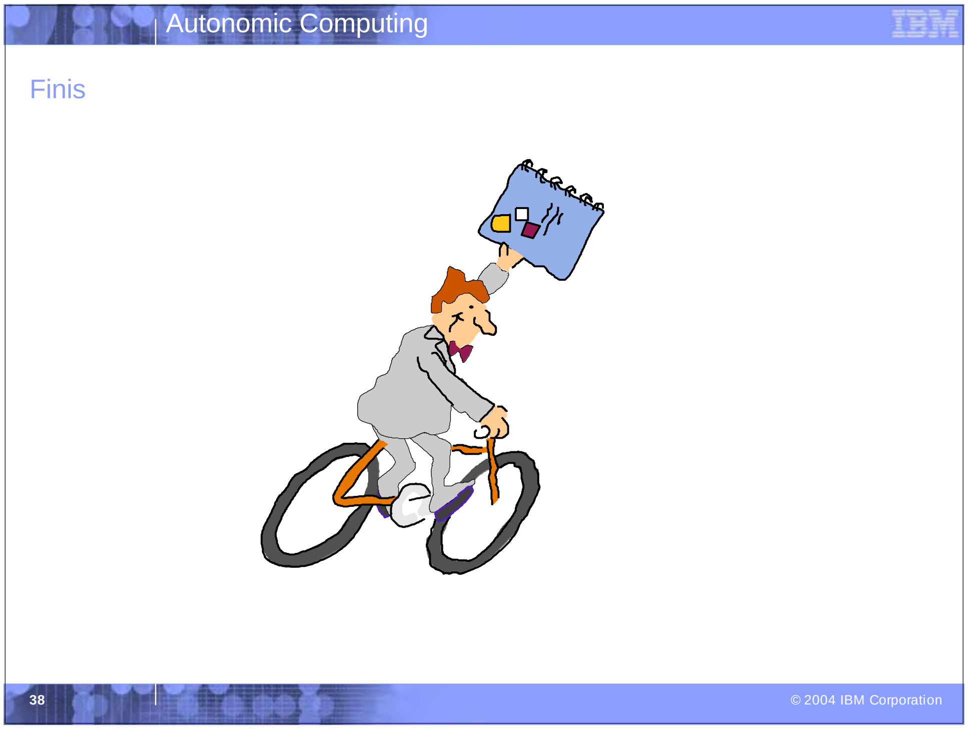

Autonomic Computing

Finis

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