PERVASIVE DATA MANAGEMENT

INTRODUCTION

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COURSE OUTLINE

- **GOAL**
  - **To introduce students to advanced topics through a personal monographic study**
- **TOPICS**
  - **Pervasive Systems functionality and architectures**
  - **Distributed Data Management**
  - **Real-Time Databases**
  - **Main Memory Databases**
  - **Embedded Databases**
  - **Data Management in WSNs**
  - **Data Streams Management Systems**
  - **Mobility issues**
  - **Context modeling and Context-Aware Information tailoring**

COURSE OUTLINE

- **TEACHING MODALITIES**
  - **Lectures and seminars (28 hrs), group homework research (max. 2 per group) and plenary class discussions of the results (10 hrs)**

- **EXAM MODALITY**
  - **Evaluation of the homework and of its presentation or development of a small project on the course topics (about 50 man/hours)**

- **LECTURERS**
  - **Fabio A. Schreiber**
  - **Other researchers**

- **COURSE WEB SITE**
  - **http://home.deib.polimi.it/schreibe/Pervasive DM/index.htm**

COURSE IN THE CURRICULUM

DATA BASES 1 → DATA BASES 2 → DATA MANAG. FOR THE WEB

DATA BASES 2 → TECH. INFO. SYS.

EMBEDDED SYSTEMS

DISTRIBUTED SYSTEMS

INFO. SYSTEMS

TECH. INFO. SYS. → **PERVASIVE DATA MANAG.**

**LAUREA
(B.sc)**

**LAUREA MAGISTRALE
(M.sc)**
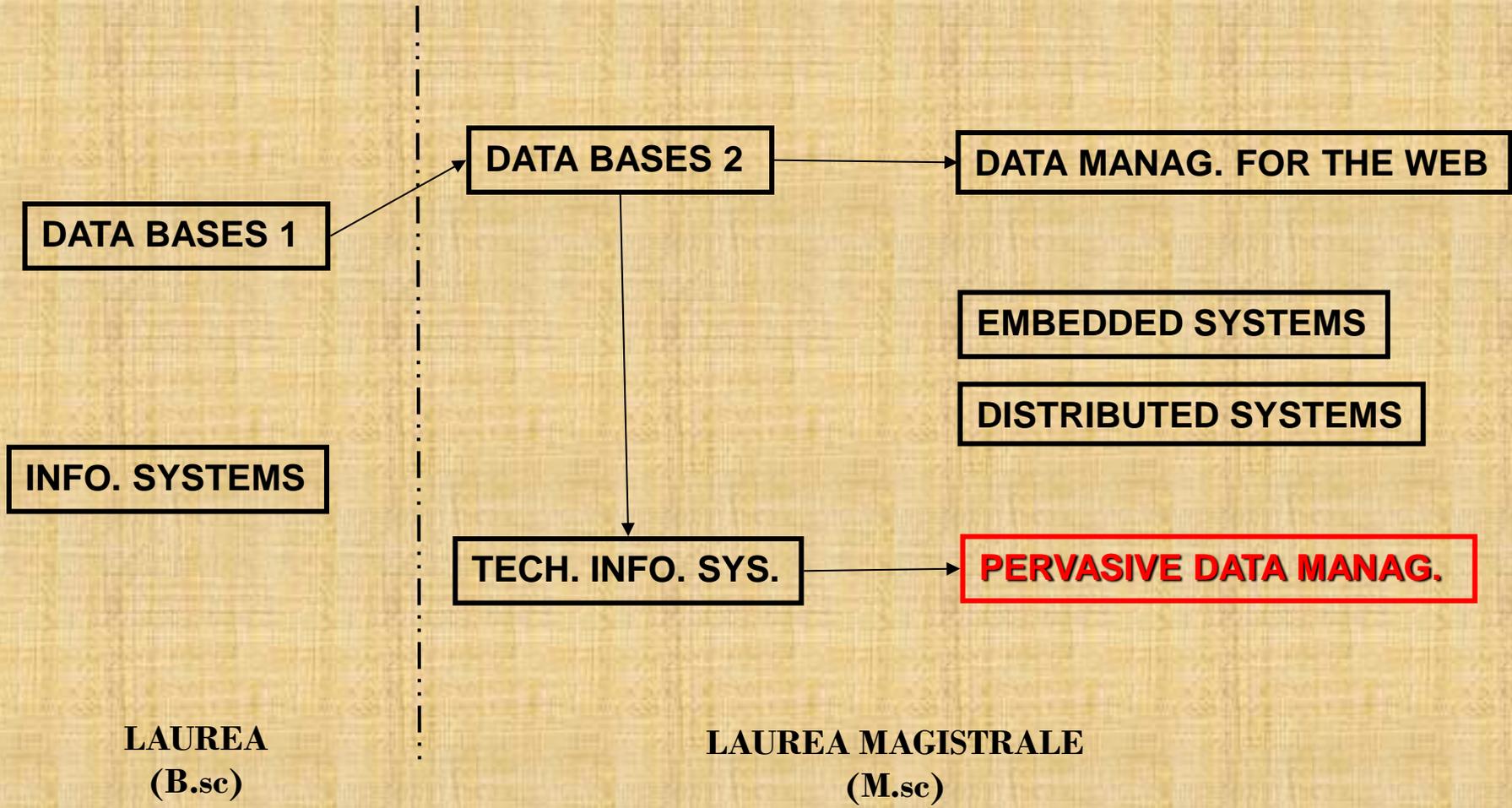
INFORMATION MANAGEMENT TECHNOLOGIES

PDM

INFORMATION SYSTEMS ANALYSIS → DATA INTEGRATION → DISTRIBUTED ETHEROGENEOUS DATA MANAGEMENT

DATA WAREHOUSE

DECISION SUPPORT SYSTEMS

DATA MINING

•REAL-TIME
•MAIN MEMORY
•TEMPORAL ISSUES

EMBEDDED SISTEMS

WIRELESS SENSORS NETWORKS

MOBILE AND CONTEXT-AWARE COMPONENTS

NON STRUCTURED SEMISTRUCTURED AND MULTIMEDIAL INFORMATION

WEB INFORMATION SYSTEMS

INFORMATION RETRIEVAL SISTEMS

INTRODUCTION TO PERVASIVE SYSTEMS

PERVASIVE
PER – VADERE

THROUGH   **TO GO**

- **Webster Dictionary**
  – **TO PERMEATE**
  – **TO BE DIFFUSED THROUGHOUT**

- **Devoto – Oli Dictionary**   **(translated from Italian)**
  – **ABLE TO DIFFUSE IN DOMAINS AND ASPECTS WHICH WERE ONCE ALIENS**
  – **TO DIFFUSE IN ORDER TO MODIFY AND CHARACTERIZE THE ATMOSPHERE OR THE PHYSIOGNOMY OF A WHOLE DETERMINED AMBIENT**
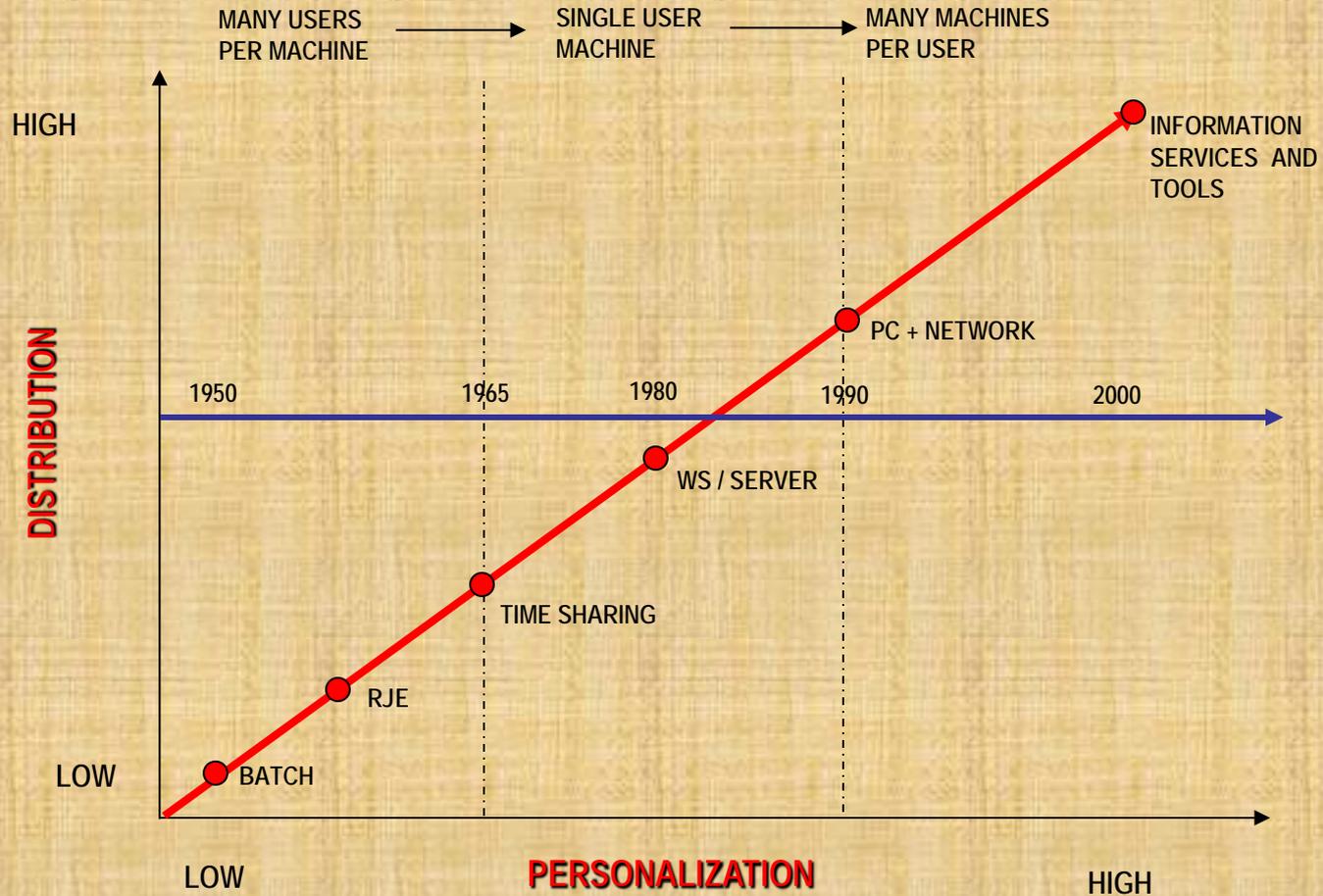
THE TECHNOLOGY LIFE CURVE

Adapted from D. A. Norman

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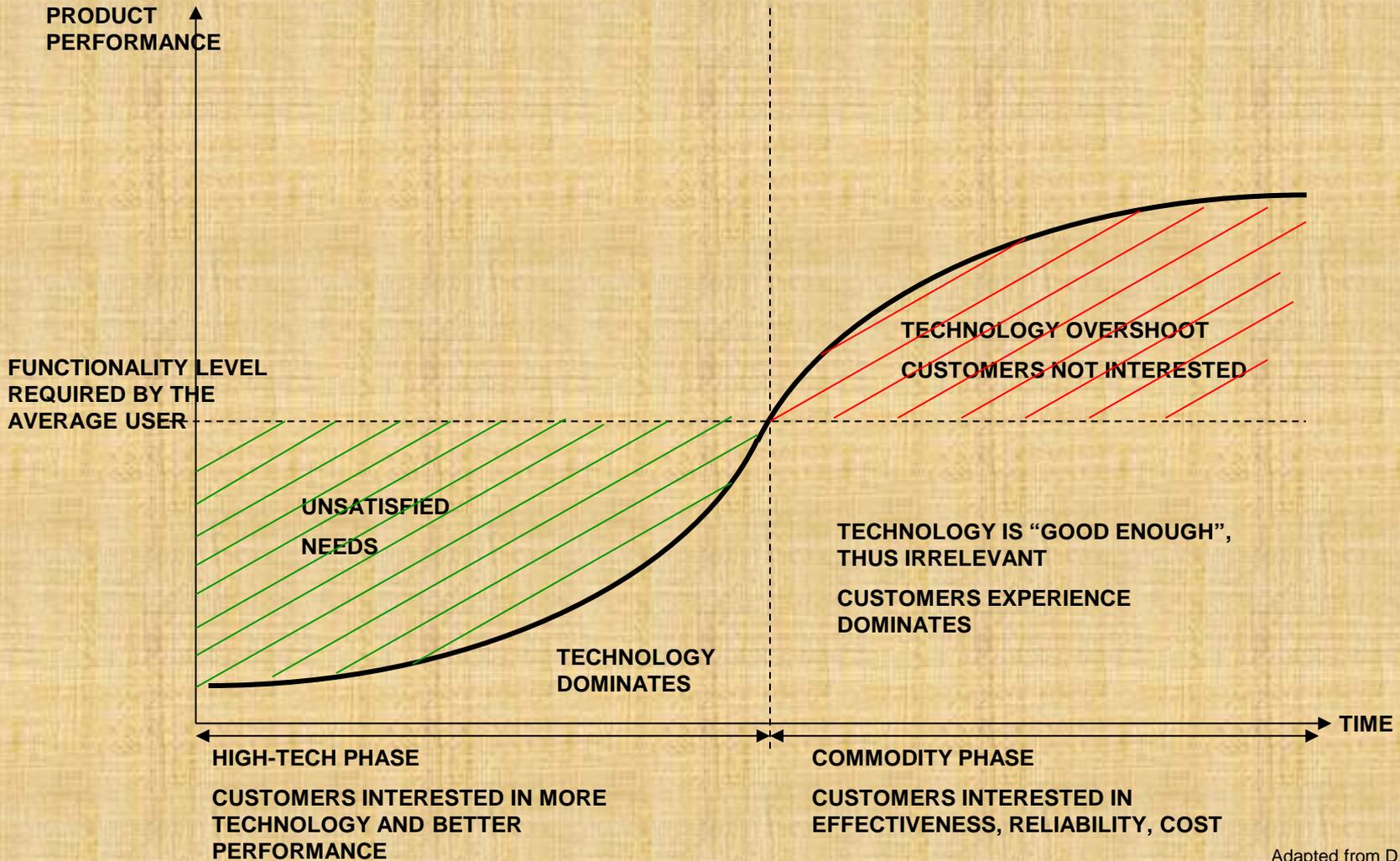
THE CUSTOMERS LIFE CURVE
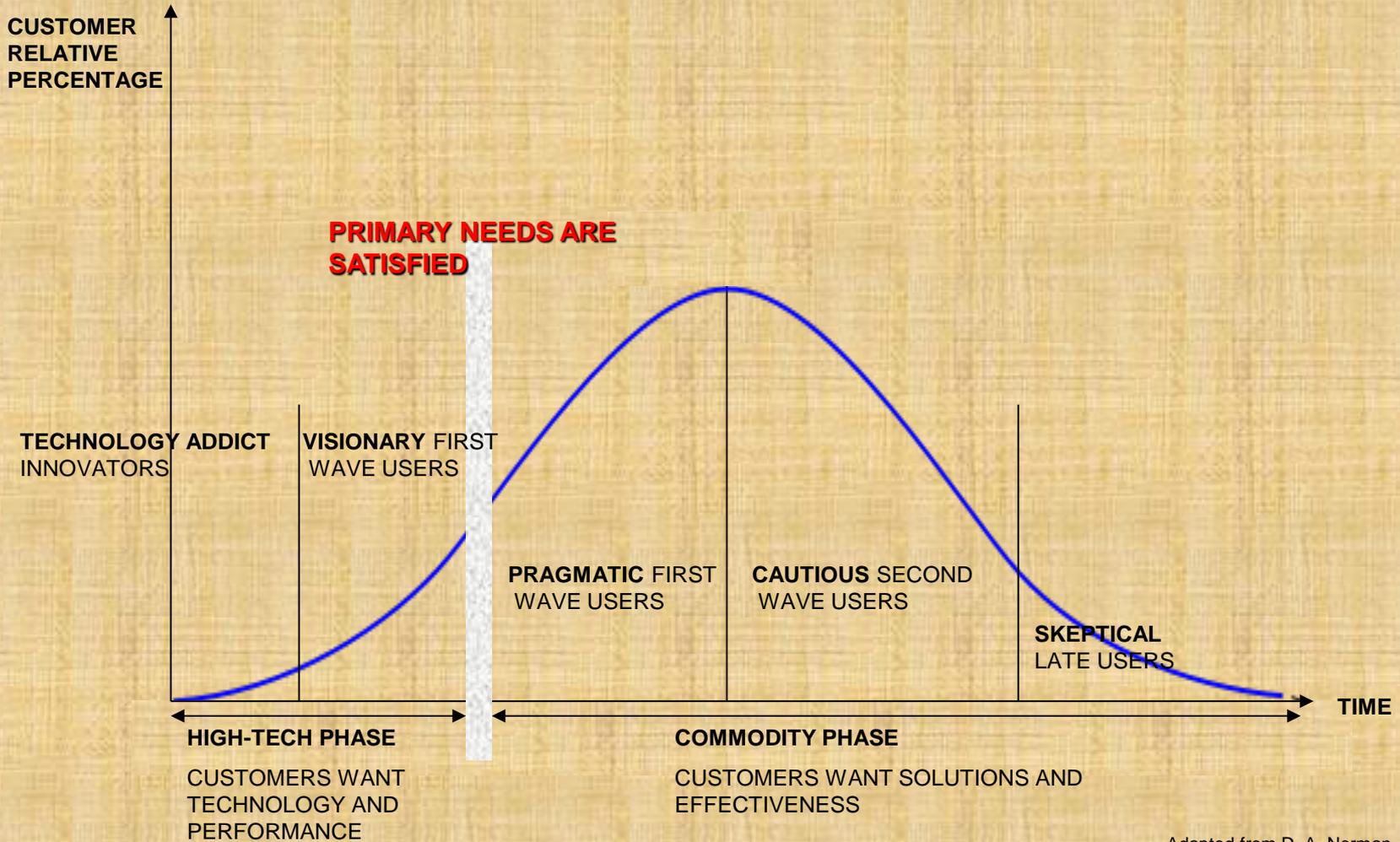
Adapted from D. A. Norman

THE ARCHITECTURE OF A MODERN INFORMATION SYSTEM

SERVER

LOCAL NETWORK

INTERNAL NETWORK

FIREWALL

FRONT END

WIDE BAND

DIGITAL NETWORKS

NARROW BAND

ANALOGICAL NETWORKS

REST OF THE WORLD

WIRELESS NETWORKS

LOCAL NETWORK

SERVER

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PDM intro 10
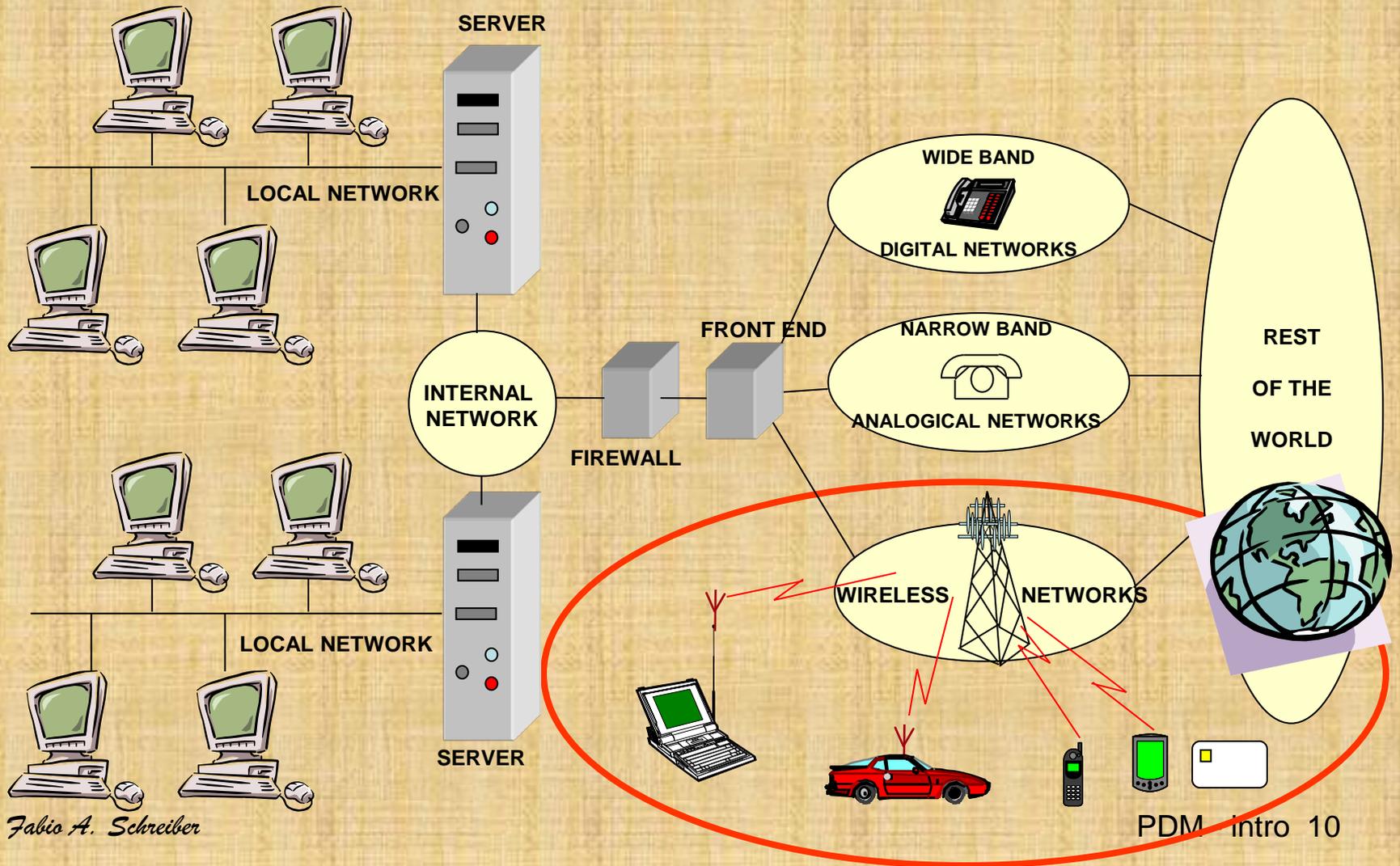
THE NEW TECHNOLOGICAL ENVIRONMENT

EMBEDDED SYSTEMS

MOBILITY
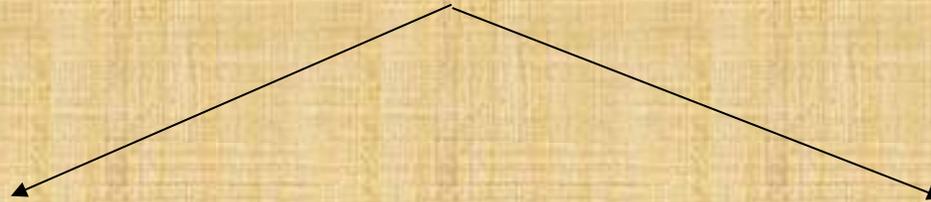
SMALL DEVICES → **CONTEXT AWARENESS**

THE INTERNET OF THINGS

- More objects are becoming embedded with sensors and gaining the ability to communicate.

- The resulting information networks promise to create new business models, improve business processes, and reduce costs and risks.

[M. Chui, M. Löffler, and R. Roberts,

McKinsey Quarterly 2010 No 2]

McKinsey Quarterly

These networks churn out *huge volumes of data* *that flow to computers for analysis.*
When objects can both sense the environment and communicate,
they become tools for *understanding complexity and responding to it swiftly.*

...*these physical information systems* are now beginning to be deployed, and some of them even work largely without human intervention.
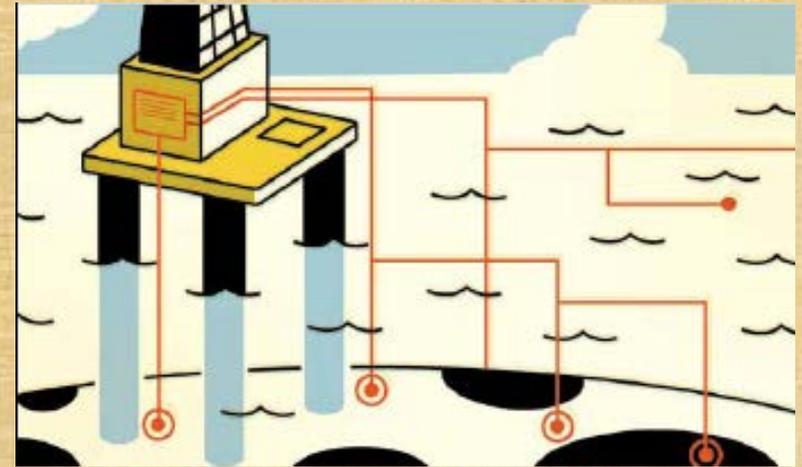
PERVASIVE SYSTEMS

- ALLOW THE COMPUTER TO VANISH INTO THE BACKGROUND

- A FUNDAMENTAL CONSEQUENCE NOT ONLY OF TECHNOLOGY, BUT OF HUMAN PSYCHOLOGY

- ONLY WHEN THINGS DISAPPEAR (i.e. THE USER IS NO MORE AWARE OF THEIR PRESENCE) WE ARE FREED TO USE THEM WITHOUT THINKING AND TO FOCUS ON NEW GOALS

- A TYPICAL CAR HAS SOMETHING AS 20 ELECTRIC MOTORS AND 10 COMPUTERS ABOARD, BUT WHO PERCEIVES THEM?

Mark Weiser, 1991

PERVASIVE SYSTEMS

- "**Pervasive computing is roughly the opposite of virtual reality. Where virtual reality puts people inside a computer-generated world, pervasive computing forces the computer to live out there in the world with people.**"

Mark Weiser, 1991

PERVASIVE SYSTEMS

- **CELLULAR PHONES (VOICE)**
  - TEXT (SMS)
  - VIDEO
  - GPS LOCATOR
- **PERSONAL DIGITAL ASSISTANTS (COMPUTATION)**
  - GPS LOCATOR
  - ACCELEROMETER
- **DIGITAL WATCHES (TIME)**
  - HEARTBEAT MONITOR
  - TEMPERATURE
  - ATHMOSPERIC PRESSURE (ALTITUDE)
  - ODOMETER (TRAVELLED DISTANCE)
- **TRANSPORTATION PASSES**
- **CAR CONTROL AND DRIVER ASSISTANTS**
- **……………………………………………………**

INTELLIGENT PERVASIVE SPACES

SOCIAL AND PHYSICAL SPACES WITH ENHANCED CAPABILITY THROUGH ICT FOR HUMANS TO INTERACT WITH THE BUILT ENVIRONMENT

Liu, 2008

- SOCIAL AND PHYSICAL INTERACTION ENVIRONMENT
- AUTOMATICALLY COMPUTING AND DYNAMICALLY ADJUSTING TO THE SPACES TO SUPPORT DIFFERENT ACTIVITIES
- COMMUNICATING WITH OTHER SERVICE SYSTEMS (SECURITY, ACCESS CONTROL, LIFTS, PARKING, …)
- SUSTAINABLE MANAGEMENT (ENERGY, WATER, WASTE DISPOSAL, POLLUTION, …)

PERVASIVE SYSTEMS

- **THE COMPUTER BECOMES PART OF THE INFRASTRUCTURE**
  - **THE MIDDLEWARE OF A PERVASIVE SYSTEM HIDES THE HETEROGENEITY OF HUNDREDS OF DEVICES MAKING THEM TRANSPARENT TO THE APPLICATION**

- **THE PERCEPTION OF THE ENVIRONMENT MAKES THE SYSTEM AUTONOMIC AND PROACTIVE**
  - **CONTEXT-AWARE**
  - **REACTIVE**
  - **SELF-ADAPTING**

PERVASIVE SYSTEMS COMPONENTS

APPLICATION DOMAINS

MIDDLEWARE AND SERVICES

PERVASIVE INFORMATION SYSTEM

ENABLING TECHNOLOGIES

DEVICES   TRANSMISSION   NETWORKING
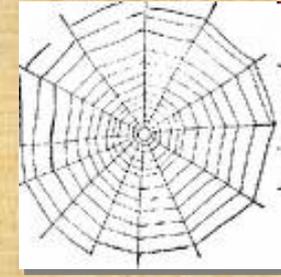
PERVASIVE SYSTEMS ISSUES

- **APPLICATION DOMAINS**
  – INNOVATIVE APPLICATIONS
  – SOCIAL AND ECONOMIC ASPECTS AND MODELS
  – VIRTUAL AND IMMERSIVE SYSTEMS

- **MIDDLEWARE AND SERVICES**
  – ADAPTIVE, AUTONOMIC AND CONTEXT-AWARE COMPUTING
  – ENERGY EFFICIENT AND GREEN COMPUTING
  – HUMAN-COMPUTER INTERACTION
  – SERVICES AND AGENT TECHNOLOGIES
  – SOFTWARE ENGINEERING ASPECTS
  – SECURITY AND PRIVACY

- **ENABLING TECHNOLOGIES**
  – AD-HOC NETWORKS AND COMMUNICATION ARCHITECTURES
  – MOBILE/WIRELESS COMPUTING SYSTEMS
  – MULTIMODAL SENSING AND CONTEXT
  – POSITIONING AND TRACKING TECHNOLOGIES
  – SENSORS AND RFID
  – WEARABLE SYSTEMS

DESKTOP VS. PERVASIVE INFORMATION SYSTEMS

DESKTOP INFO SYS	PERVASIVE INFO SYS
• PERSONAL COMPUTER (just another access device)	• MULTIPLE ARTEFACTS
• PERCEIVE SIMPLE USER INPUT	• PERCEIVE ALSO CONTEXT INFORMATION
• STATIONARY SERVICES	• SUPPORT MOBILITY

DESKTOP VS. PERVASIVE INFORMATION SYSTEMS

	DESKTOP INFO SYS	PERVASIVE INFO SYS
USER	• COMMITTED • KNOWN • TRAINED *ROLE MODEL:* OFFICE CLERK	• OPPORTUNISTIC • UNKNOWN • UNTRAINED *ROLE MODEL:* CITIZIEN
TASK	• SPECIFIC • FOCUSED ON UTILITY AND PRODUCTIVITY	• GENERIC • FOCUSED ON SERVICE DELIVERY AND EXPERIENCE
MEDIUM	• LOCALISED / FIXED • HOMOGENEOUS • *POINT AND CLICK* PARADIGM	• CONSTANT PRESENCE / NOMADIC / SPONTANEOUS, TEMPORARY P2P NETWORKING • HETEROGENEOUS • NATURAL INTERACTION & MULTIMODAL
SPACE	• CYBERNETIC	• PHYSICAL
PRODUCT	• VIRTUAL	• TANGIBLE AND VIRTUAL
TIME	• REACTIVE	• PROACTIVE

Adapted from P. E. Kourouthanassjs

DATA MANAGEMENT SYSTEMS FUNCTIONALITY
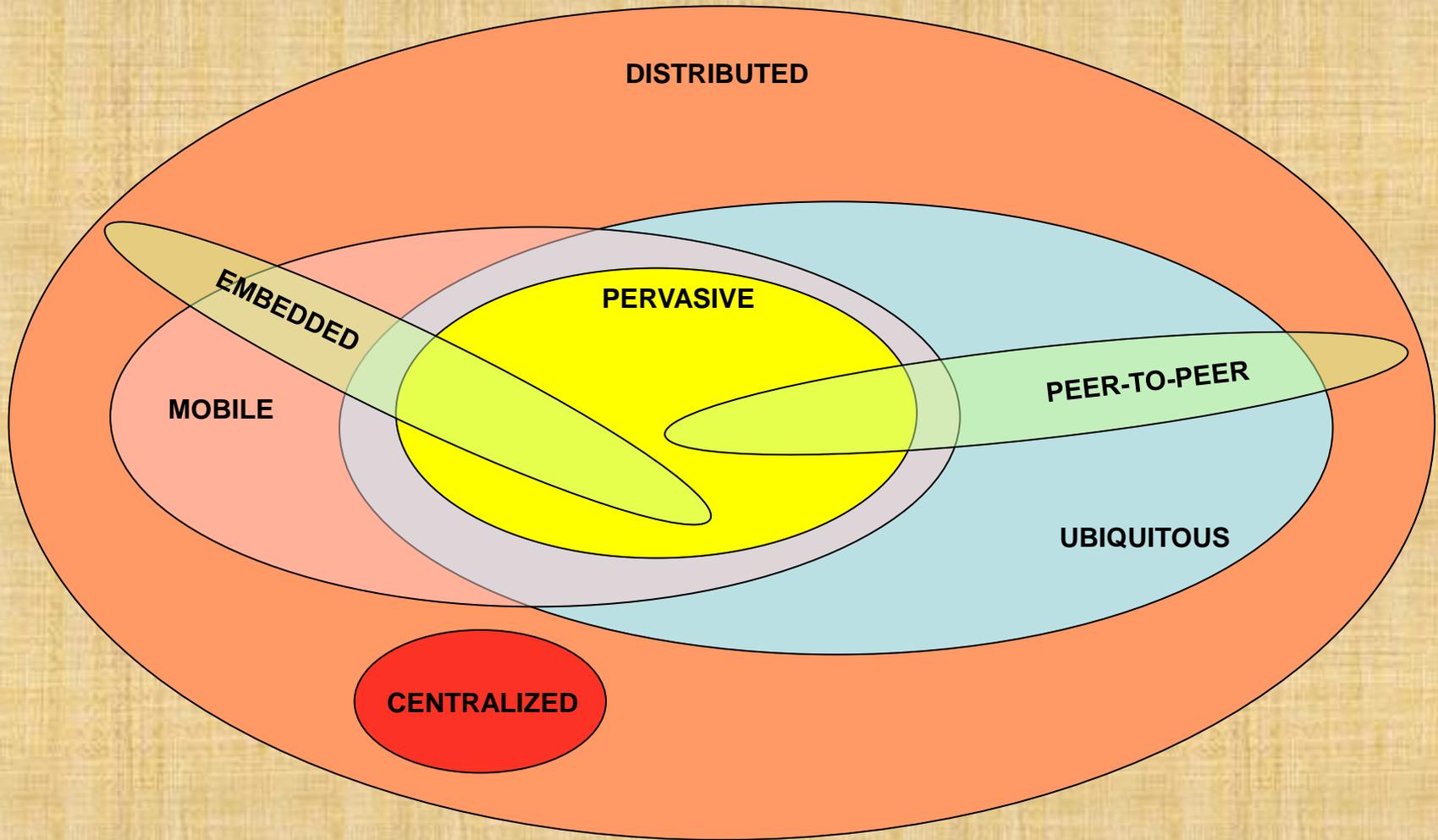
PERVASIVE DATA MANAGEMENT

- **INSTANTANEOUS AND COMPLETE ACCESS TO ANY INFORMATION AT ANYTIME AND ANYWHERE**
  - **HIGHLY DYNAMIC ENVIRONMENTS WHERE BOTH DATA AND SOURCE AVAILABILITY VARY OVER LOCATION AND TIME**

- **REVERSED PARADIGM WITH RESPECT TO DISTRIBUTED DATABASES**
  - **NO MORE PASSIVE DB AND ACTIVE USERS**
  - **DEVICES ARE BOTH PRODUCERS AND CONSUMERS OF DATA**
    - **DATA OBJECTS STORED ON MOBILE DEVICES WHICH PROCESS THE INCOMING DATA WHILE LOOKING FOR INFORMATION OF INTEREST TO ITS USER**

PERVASIVE DATA MANAGEMENT

DATA MANAGEMENT ISSUE	MOBILE COMPUTING **PERVASIVE COMPUTING**
APPLICATIONS	**NEED TO ADAPT TO CHANGES IN SYSTEM CONTEXT**
TRANSACTIONS	**NEW MODELS TO CAPTURE MOBILITY**
RECOVERY	•**FREQUENT NETWORK PARTITIONING** •**VOLUNTARY SHUTDOWN IS NOT A FAILURE** •**NO FIXED SET OF ENTITIES ALWAYS AVAILABLE** •**MORE LOGGING** •**RECOVERY TECHNIQUES FROM HANDOFF DISCONNECTIONS**
REPLICATION	•**DIFFERENT CONSISTENCY CONSTRAINTS** •**NEW TECHNIQUES FOR CACHE UPDATE (FREQ. DISCONNECTIONS)**
QUERY PROCESSING	•**LOCATION DEPENDENT** •**DIFFERENT COST FACTORS** •**RESPONSES RETURNED TO DIFFERENT LOCATIONS** •**ADAPTIVE TECHNIQUES NEEDED**
NAME RESOLUTION	**NEW GLOBAL NAME STRATEGY (MOBILITY & DISCONNECT)** **NO GLOBAL CATALOG AND SCHEMA (USE OF ONTOLOGIES)**

EMBEDDED DBMS FEATURES

REAL TIME

ACTIVE

MAIN MEMORY

EDBMS

CONTEXT AWARE

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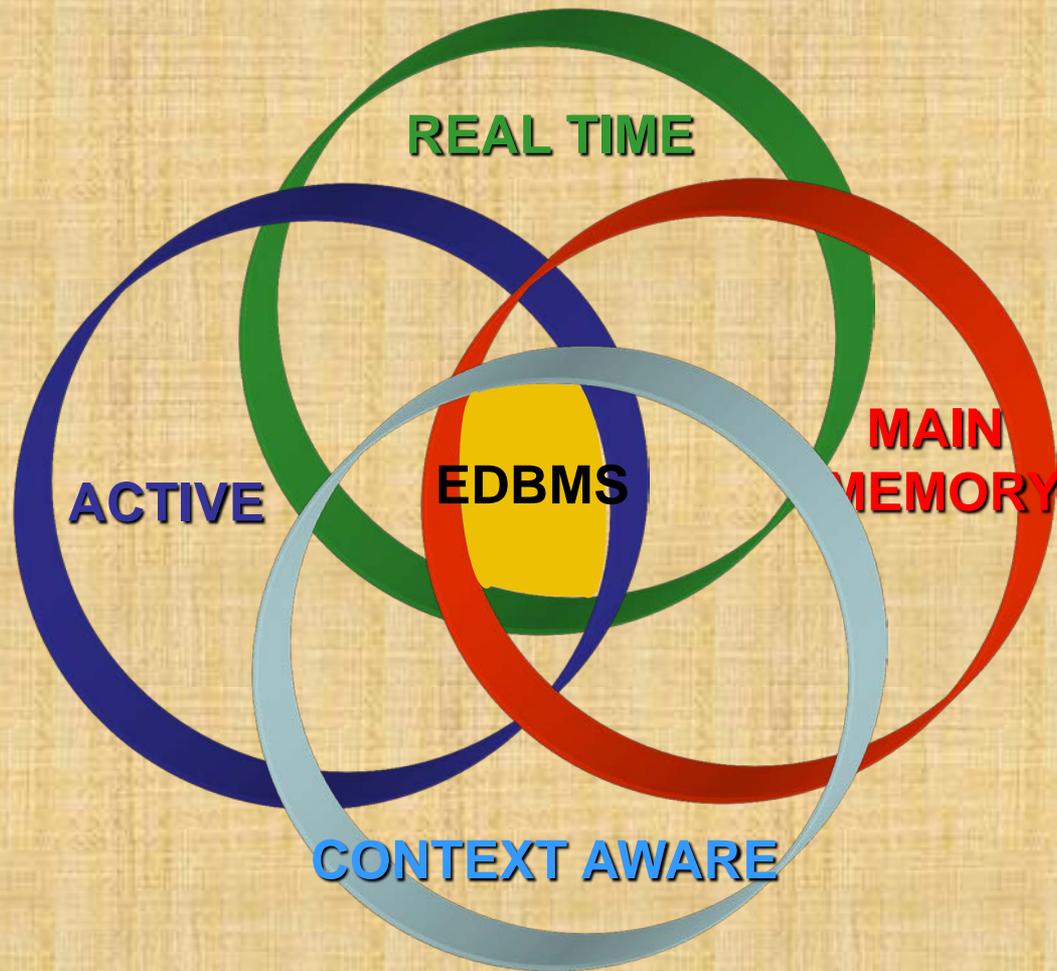
EMBEDDED DBMS FUNCTIONALITY

FEATURES APPLICATION	REAL TIME	ACTIVE	MAIN MEMORY
PROCESS / DEVICE CONTROL	YES HARD / FIRM	YES	POSSIBLY
MOBILE / INTERNET APPLICATIONS	YES FIRM / SOFT	YES	POSSIBLY
SMART CARD APPLICATIONS	NO / SOFT	NO	YES

PERVASIVE DATA MANAGEMENT

MOBILITY

- **SPATIO-TEMPORAL VARIATIONS OF DATA AND DATA-SOURCES AVAILABILITY**

- **LACK OF GLOBAL CATALOG AND SCHEMA**

- **NO GUARANTEE OF RECONNECTION**

- **NO GUARANTEE OF COLLABORATION**

BIBLIOGRAPHICAL REFERENCES 1

- B. Babcock et Al. – *Models and Issues in Data Stream Systems* – Proc. ACM PODS, pp. 1-16, Madison 2002

- Y. Bai, H. Thakkar, C. Luo, H. Wang, C. Zaniolo – *A Data Stream Language and System Designed for Power and Extensibility* – Proc. of the ACM 15th Conference on Information and Knowledge Management (CIKM'06), 2006

- G. Bernard et Al. – *Mobile Databases: a Report on Open Issues and Research Directions* - ACM SIGMOD Record, (2004) http://lpd.epfl.ch/site/publications/

- B. Chandramouli et Al. – *Data Stream Management Systems for Computational Finance* – IEEE Computer, Vol. 43, n. 12, 2010

- M. Cherniack, M. Franklin, S. Zdonik – *Data Management for Pervasive Computing* – 27th VLDB Conference tutorial, Roma, Sept. 2001

- C.A. da Costa, A. Corrêa Yamin, C.F.R. Geyer – *Toward a General Software Infrastructure for Ubiquitous Computing* – Pervasive Computing, Vol. 7, No. 1, 2008

- L. Golab and M. Tamer Özsu – *Issues in Data Stream Management* – SIGMOD Record, Vol. 32, No. 2, June 2003

- J. Hyde – *Data in Flight* – Communications of ACM, Vol. 53, n.1, Jan 2010

- S. Ilarri, E. Mena, A. Illarramendi – Location-Dependent Query Processing: Where We Are and Where We Are Heading – ACM Computing Surveys, Vol. 42, n. 3, 2010

BIBLIOGRAPHICAL REFERENCES 2

- P. E. Kourouthanassis, G. M. Giaglis – *A Design Theory for Pervasive Information Systems* – Proc. Int. Workshop on Ubiquitous Computing (ICEIS 2006), pp. 62-70, 2006

- Y. Law, H. Wang, C. Zaniolo – *Query Languages and Data Models for Database Sequences and Data Streams* – Proc. 30° VLDB Conf., pp. 492-503, 2004

- K. Liu – *Pervasive informatics in intelligent spaces for living and working* – IEEE Int. Conf. On ServiceOperations and Logistics, and Informatics, 1, pp. XVIII-XIX, 2008

- D. A. Norman – *The Invisible Computer* – MIT Press, Cambridge 1998

- M. A. Olson - *Selecting and Implementing an Embedded Database System* - IEEE Computer, vol. 33, n. 9, pp. 27-34, (2000)

- F. Perich, A. Joshi, T. Finin, Y. Yesha – *On Data Management in Pervasive Computer Environments* – IEEE TKDE, Vol. 16, No. 5, pp.621-633, 2004

- D. Pfoser, C.S. Jensen, Y. Theodoridis – *Novel Approaches to the Indexing of Mobile Objects trajectories* – Proc VLDB 2000, pp. 395-406

BIBLIOGRAPHICAL REFERENCES 3

- **F.A. Schreiber, R. Camplani, M. Fortunato, M. Marelli, F. Pacifici - PERLA: a Data Language for Pervasive Systems- Proc. of the Sixth Annual IEEE International Conference on Pervasive Computing and Communications (PerCom 2008), Hong Kong, pp. 282-287, 2008.**

- **N. Trigoni, a. Guitton, A. Skordylis – *Querying of Sensor Data* – in J. Gama, M. M. Gaber – Learning from Data Streams, Springer, 2007**

- **M. Weiser – *The Computer for the 21th Century* – Scientific American, Vol. 265, No. 3, pp. 94-104, 1991**

- **O. Wolfson – *Moving Objects Information Management: The Database Challenge* –** http://www.cs.uic.edu/%7Ewolfson/mobile_ps/ ngits02.pdf

- **W. Xue, Q. Luo, L. M. Ni – *Systems Support for Pervasive Query Processing* – Proc. 25° Int. Conf. on Distributed Computing Systems (ICSCS05), IEEE, 2005**