Contextware

Bridging Physical and Virtual Worlds

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Title: the world is not a desktop

"... What is the metaphor for the computer of the future?
The intelligent agent?
The television (multimedia)?
The 3-D graphics world (virtual reality)?
The StarTrek ubiquitous voice computer?
The GUI desktop, honed and refined?
The machine that magically grants our wishes?

I think the right answer is "none of the above", because I think all of these concepts share a basic flaw: they make the computer visible. ..."

-- Perspectives article for ACM Interactions
-- Weiser, November 7, 1993 10:20 pm PST

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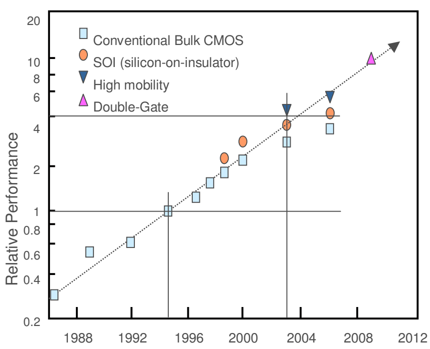
Outline

- Observations
- Vision
- Challenges
- Approach

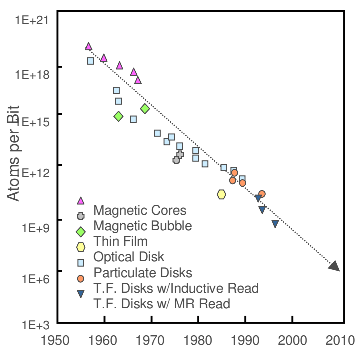
Observation 1: Moore's Law (since 1965)

Processing speed doubles every 18 months
Key technology parameters “double” every three years

CPU Performance

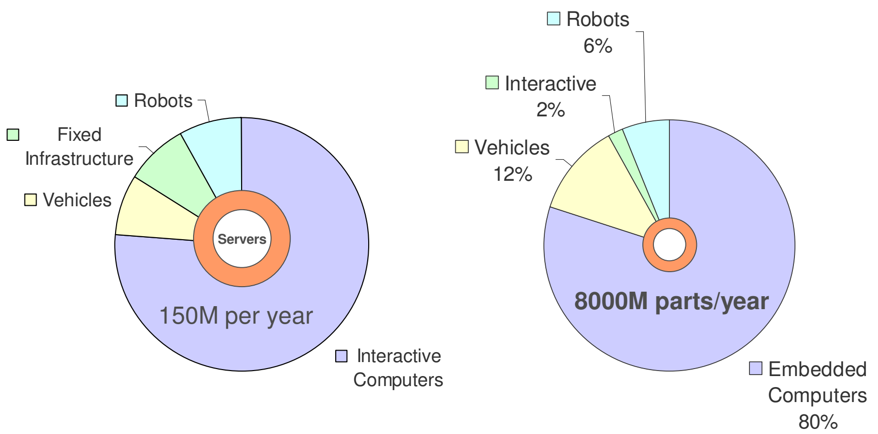


Core Capacity



Trends to continue for at least next 10 years !
after 2010: 3D ICs, Optical-, Quantum-, Molecular-, Genetic, DNA-Computing ...

Observation 2: Embedded Systems Software Crisis



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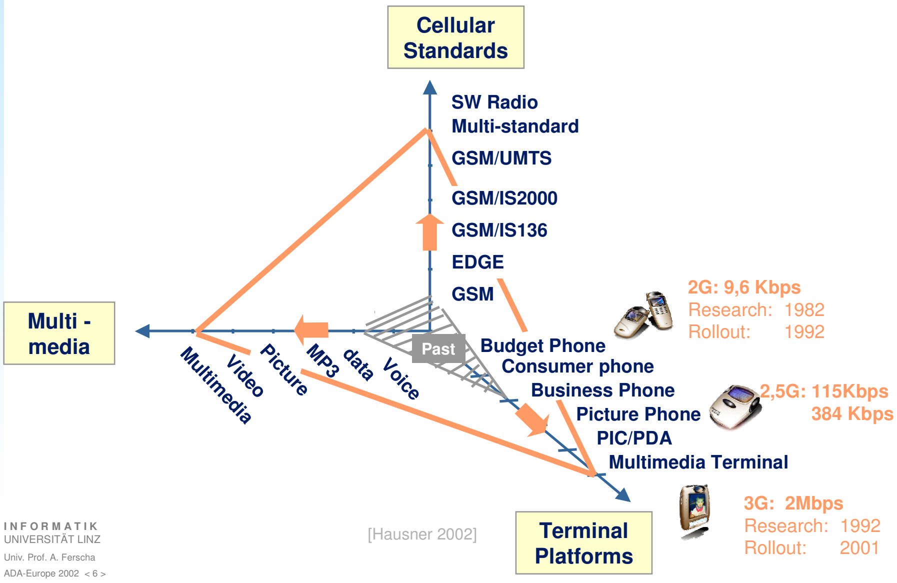
[CACM 5/2000]

Observation 3: Mobile Communication

Convergence of Standards, Information and Communication



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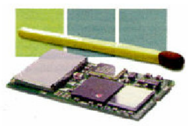
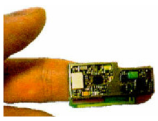
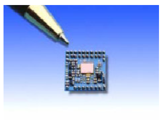
[Hausner 2002]

Observation 4: Wireless Communication

Category	Home-RF (1.09)	IEEE 802.11	Bluetooth	IrDA (AIR)
Market	Home WAN	WLAN	Cable	Cable
Techn.	RF 2.4 GHz FHSS	RF 2.4 GHz FHSS,DSSS	RF 2.4GHz FHSS	Optical 850nm
Power	20 dBm	20 dBM	0/20 dBm	?
Rate	0.8/1.6 M	11 M	1 M	4 M / 115 K
Distance	50 m	30 m	0-10/100 m	0-3/5 m
Topology	128 devices CSMA	128 devices CSMA	8 devices Pt-to-MP	10 devices Pt-to-MP
Security	Optional	Optional	Authentication, key mgmt, encryption	Application Layer

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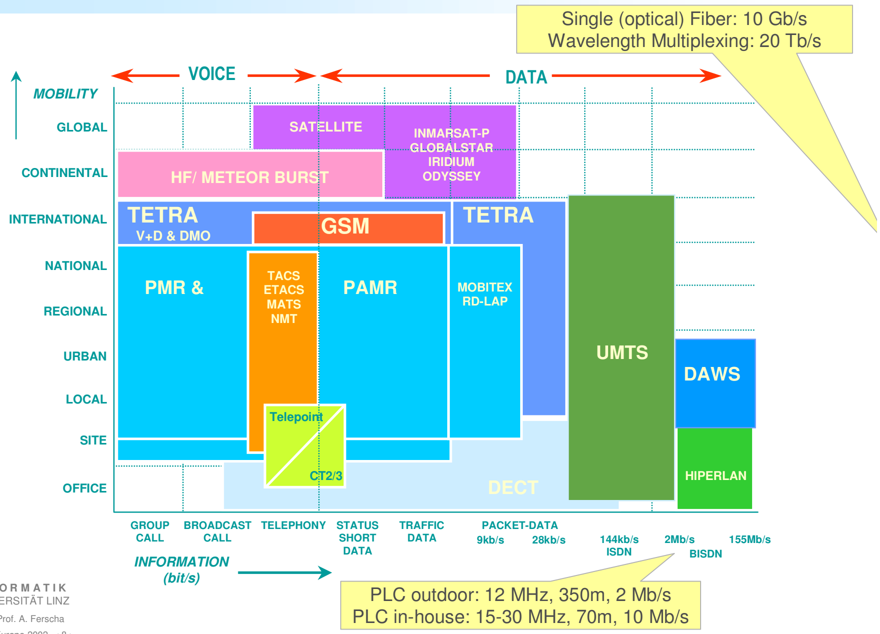
Observation 5: Seamless Access



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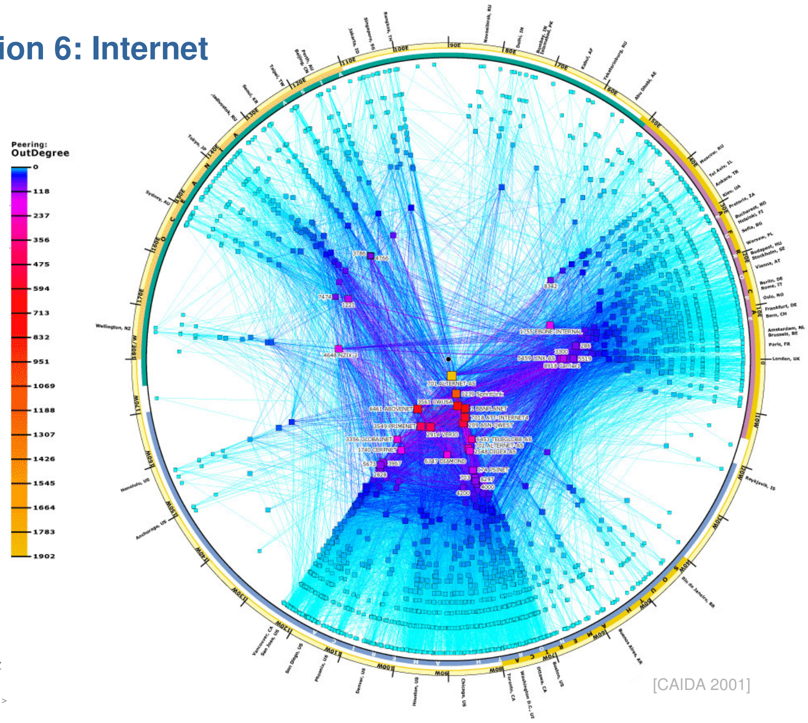
Observation 6: Internet



[CAIDA 2001]

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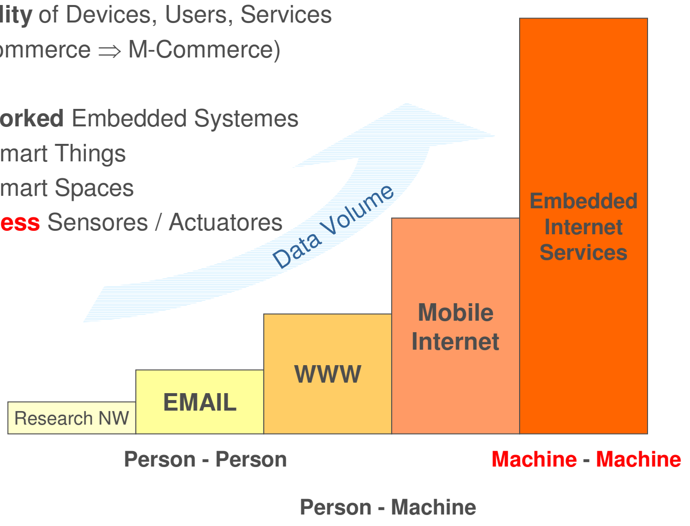
Qualitative Growth: Embedded Internet

- **Mobility** of Devices, Users, Services
  (E-Commerce ⇒ M-Commerce)
- **Networked** Embedded Systemes
  - Smart Things
  - Smart Spaces
- **Wireless** Sensores / Actuatores



[F. Mattern, 2001]

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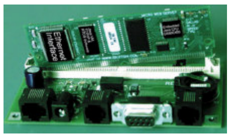
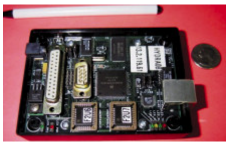
Observation: Embedded Internet

Tiny Web Server



Dallas Semiconductors
Web Server



HYDRA Web Server
(Xerox PARC)

Web Servers on a Chip

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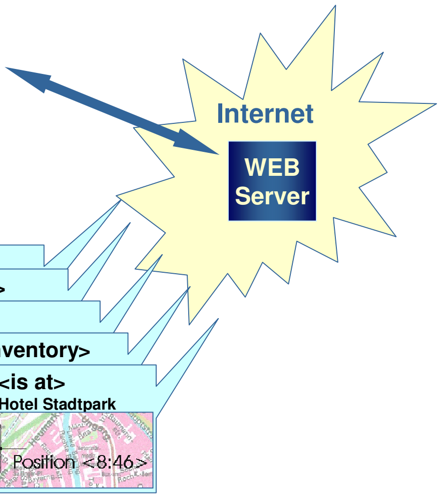
Example: Embedded Internet

- **Invisible Processors**
  leightweight, small, cheap, low/no power

- **in almost all Everyday Objects**
- **Wireless** Interconnect
- **Continuous** Connectivity



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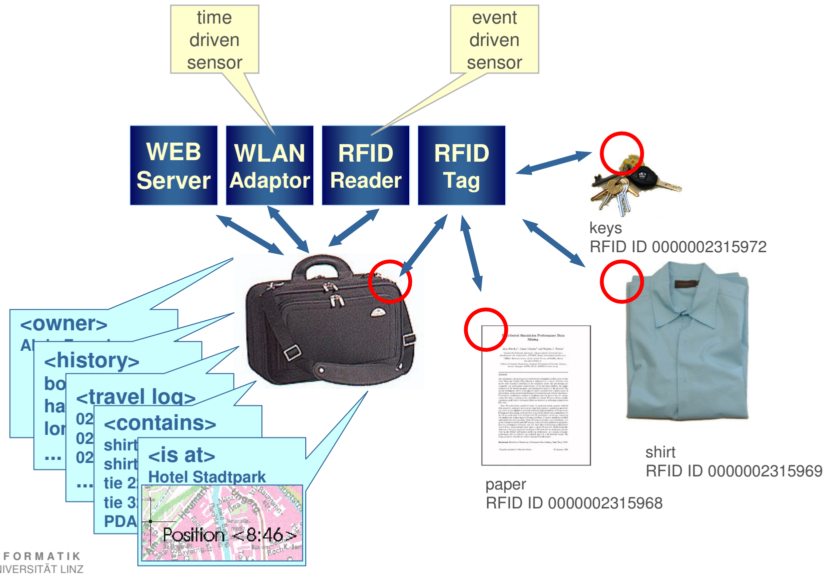
Example: Embedded Internet



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Vision: A world where ...

... bits and atoms are merged

... physical objects interact in real time

... all the time

... everything is aware of everything

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From Awareness to Context

Awareness ... an understanding of the activities of others, which provides a context for your own activities.

[Dourish, Bellotti, CSCW'92]

... an understanding of the presence and activities of others within a shared hybrid environment, which provides a context for mutual orientation and opportunities for situative reactions.

"Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves."

"A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task."

[Dey 2000]

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What is Context?

User actions take place in contexts

- Geographical contexts (e.g., buildings, floors, offices)
- Physical contexts (e.g., lighting, noise levels, temperature)
- Social contexts (e.g., family, friends, co-workers)
- Organisational contexts (e.g., departments, projects)
- User context (e.g., profile, location, capabilities)
- Action contexts (e.g., tasks)
- Technological contexts (e.g., Java programmers)
- Time context (e.g., time of a day, week, month, season of the year ...)
- etc.

Context Computing based on two major issues:

- Context Sensing / identifying relevant context
- Using obtained context information in adaptive / reactive / proactive i.e. context aware environments

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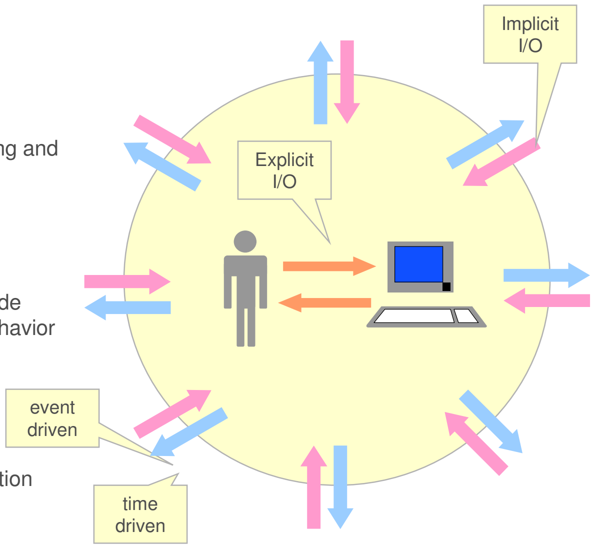
Context

- system is "aware" of physical, social etc. environment (states, events history, causalities, etc.)
- explicit I/O is monoplising and demand user attention: exploit implicit I/O (proactive background processes)
- exploit "history" to provide "intelligent" / "smart" behavior
- natural interaction' – with "knowledge"

Sensors
acquire context information
Actuators
control the environment



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Context

Context Sensing
acquire low level context information

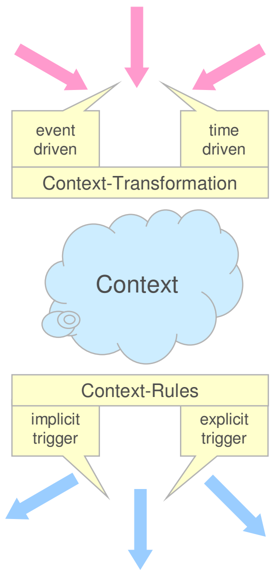
Context Transformation
transform / aggregate / interpret
low level context information

Context Representation
data structures for context information
centralized / decentralized?

[Context Dissemination]

Context Triggering
implicit / explicit
event triggering

Controlling Actuators
control the environment



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Context Sensing

Sensing low-level context information

- identification, localization / positioning, tracking
- various kind of sensors / types of sensor data

Sensing high-level context information (e.g. user´s current activity)

- Approaches
  - machine vision, camera technology, image processing
  - access profiles (e.g. consult the user´s calendar directly)
  - Artificial Intelligence techniques to recognize complex context by combining several simple low-level sensors
  - rule-based systems

Sensing context changes

- Selected issues
  - push vs. pull services for notification
  - frequency of updates
  - robustness, reliability

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Sensor Technologies

Physical Sensors: Motion, Light, Temperature, Orientation, Acceleration, ...

Biosensors: Surface Tension, Metabolic Rate, Rigidity / Spasticity of (Muscles), Breaathing, ...

Optical/Accoustical Sensors: Audio-Videodata, Noise, Voice-Imagerecognition, Scene Analysis, ...

(Electrical-) Magnetic Sensors: Identification (RFID, IrDA), Acceleration, Counter, ...

Position Sensors: GPS, dGPS, GSM, WLAN, Bluetooth, RFID, ...

Tracking: Pattern Recognition, Time Series Analysis, Reasoning, Konwledge Representation, ...

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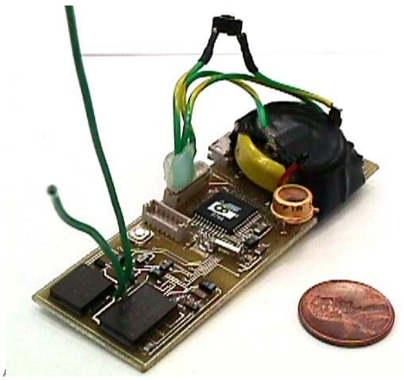
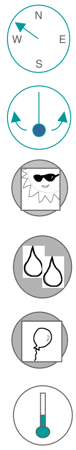
Multisensors: COTS RF Motes

- Atmel Microprocessor
- RF Monolithics transceiver
  - 916MHz, ~20m range, 4800 bps
- 1 week fully active, 2 yr @1%





- 2 Axis Magnetic Sensor
- 2 Axis Accelerometer
- Light Intensity Sensor
- Humidity Sensor
- Pressure Sensor
- Temperature Sensor

[Pister 2001]

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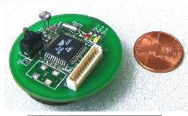
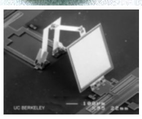
Sensor/Actuator Networks

Sensors
collect data, passive interaction with environment



Actuators
control machines, may introduce changes into environment



- redundancy increases fault tolerance (easy to replenish the system when sensor nodes fail)
- many small sensors = very large total space
- coverage area can have arbitrary shapes (including shadows, holes)
- easy way of sizing the system according to application demands
- coverage area and density can be incrementally increased
- sensing quality increases by combining information from different (spatial) perspectives
- sensing performance can be improved by combining multiple sensor types
- low-cost short-range sensor technology can be used
- sensors in close proximity to the object of interest

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Context Representation: (Early Approaches)

Merriam-Webster on context:

- 1: the parts of a discourse that surround a word or passage and can throw light on its meaning
- 2: the interrelated conditions in which something exists or occurs

Contexts considered as abstract mathematical objects [McCarthy 87, Guha 91]

- istrue(p,c) proposition p is true in some context c

Attardi's notion of context [Attardi 93]

- in(s; vp) statement s can be entailed from the viewpoint vp

Chiunchiglia's notion of Context [Chiunchiglia et. al 90, 93]

- belief contexts for multi-agent theories
- context-based framework for mental representation

.

Context Representation: (Recent Approaches)

Key-value pairs [Schilit 93]

- environment variable acting as the key, value of the variable holding the actual context data (e.g.: Mobisaic [Voelker et.al 94])

Tagged encoding

- contexts are modeled as tags ("Stick-e note") and corresponding fields (using SGML / XML) (e.g.: ConteXtML [Pascoe 98])

Object-oriented model

- based on the concept of integrating an active-object model with a hypertext information model
- contextual information is embedded as the states of the object, and the object provides methods to access and modify the states (e.g.: GUIDE System [Davies et.al 99])

Logic-based model

- context data are expressed as facts in a rule-based system (using e.g. Prolog) (e.g.: [Bacon et.al 97])

Context Transformation (Toolkit Approach)

GT Future Computing Environments (FCE) "Context Toolkit"

- general-purpose infrastructure
- framework and components for developing "context-aware" applications
  - Provides for example directory and map information to PDAs and kiosks.
- framework is analogous to GUI 'widgets' which isolate details of user interaction behind standard interfaces.

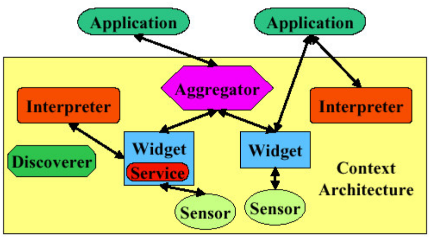
Services of the Context Toolkit

- **encapsulation** of sensors
- **access** to context data through a network API
- **abstraction** of context data through interpreters
- **sharing** of context data through a distributed infrastructure
- **storage** of context data, including history
- basic **access control** for privacy protection

Context Frameworks

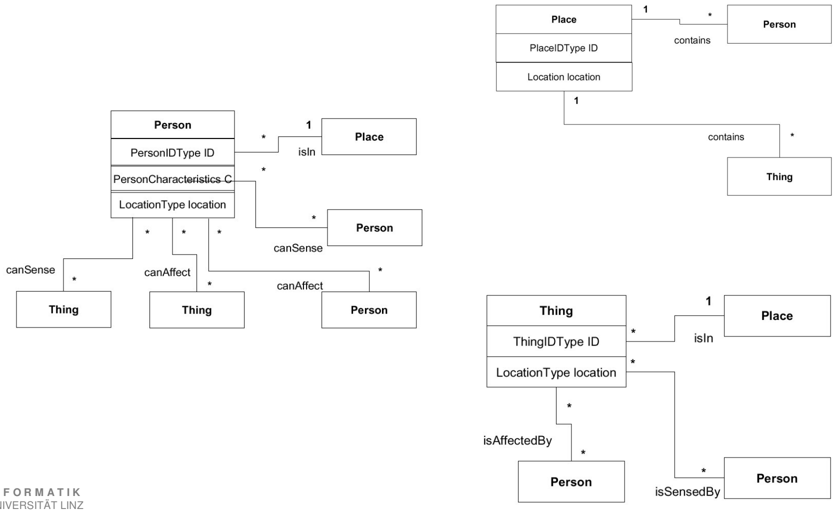
"Context Toolkit" has four main types of components:

- **Widgets:** wrap sensor devices, providing simple and standard access to sensors of many types across the network; collect context information and provide it to aggregators/applications
- **Interpreters:** transform/interpret context information
- **Aggregators:** filter data from one or more sensor, aggregate context information
- **Discoverers:** discover/locate functionality relevant for services



[Dey 2000]

The “Person – Place – Thing" Approach



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Context Representation: A Metadata Approach

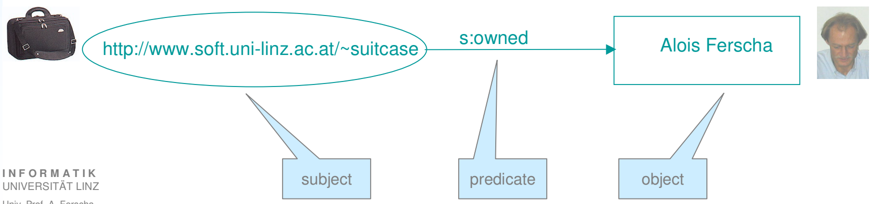
Statement

“The bag http://www.soft.uni-linz.ac.at/~suitcase is owned by Alois Ferscha”

Structure

Resource	(subject)	http://www.soft.uni-linz.ac.at/~suitcase
Property	(predicate)	http://www.schema.org/#owned
Value	(object)	"Alois Ferscha”

Representation as directed graph



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(RDF) Resource Description Framework

Resource - everything with a URI
Description - properties of these resources (associative metadata)

RDF Data Model

- Resources
  - A resource is a thing you talk about (can reference)
  - Resources have URI's
  - RDF definitions are themselves Resources
- Properties
  - slots, define relationships to other resources or atomic values
- Statements
  - "Resource has Property with Value"
  - (Values can be resources or atomic XML data)
- RDF defines three special Resources:
  - Bag unordered values rdf:Bag
  - Sequence ordered values rdf:Seq
  - Alternative single value rdf:Alt

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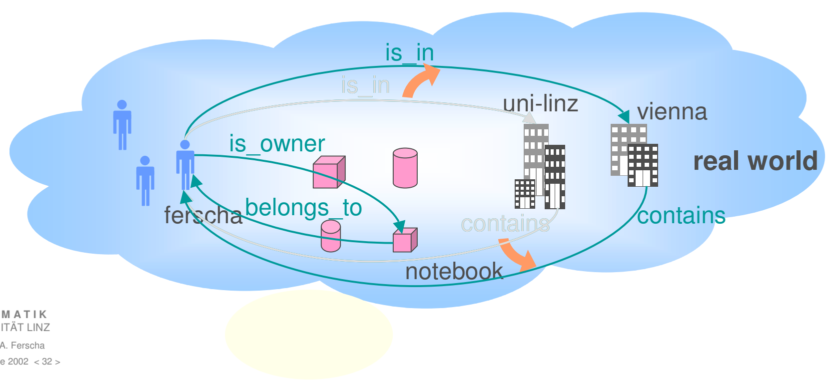
RDF Context Representation



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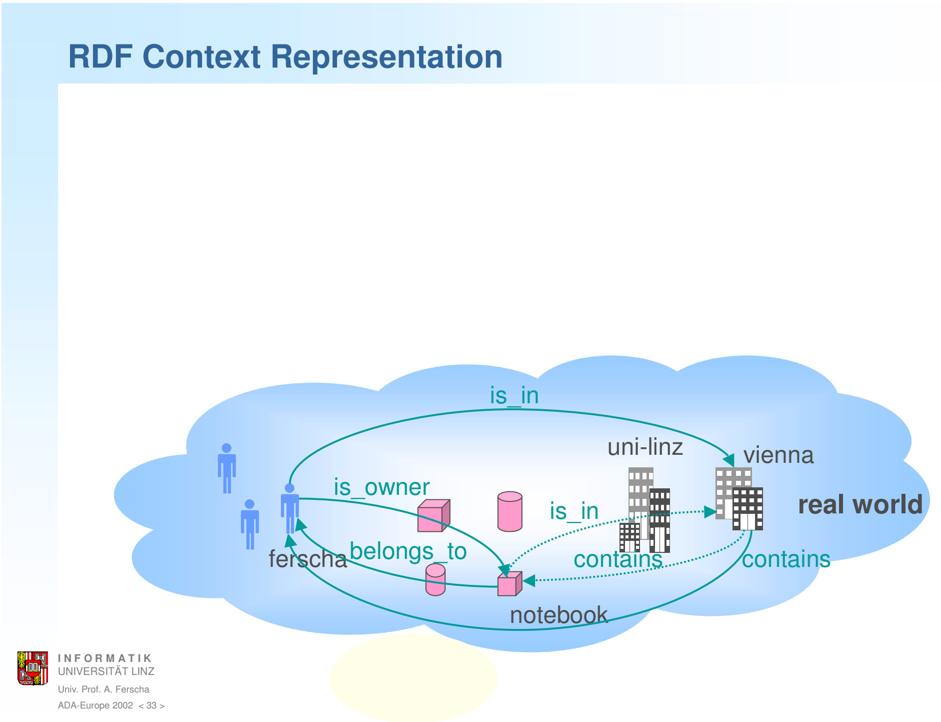
RDF Context Representation
is_in
uni-linz
vienna
is_owner
is_in
real world
fersch a
belongs_to
contains
contains
notebook
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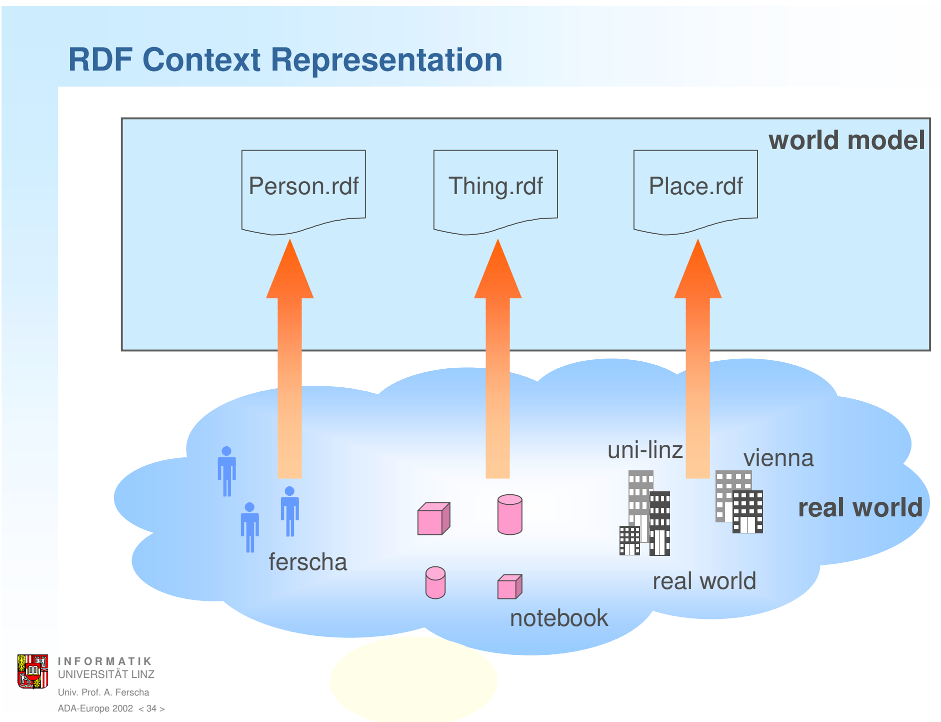
RDF Context Representation
world model
Person.rdf
Thing.rdf
Place.rdf
uni-linz
vienna
real world
ferscha
real world
notebook
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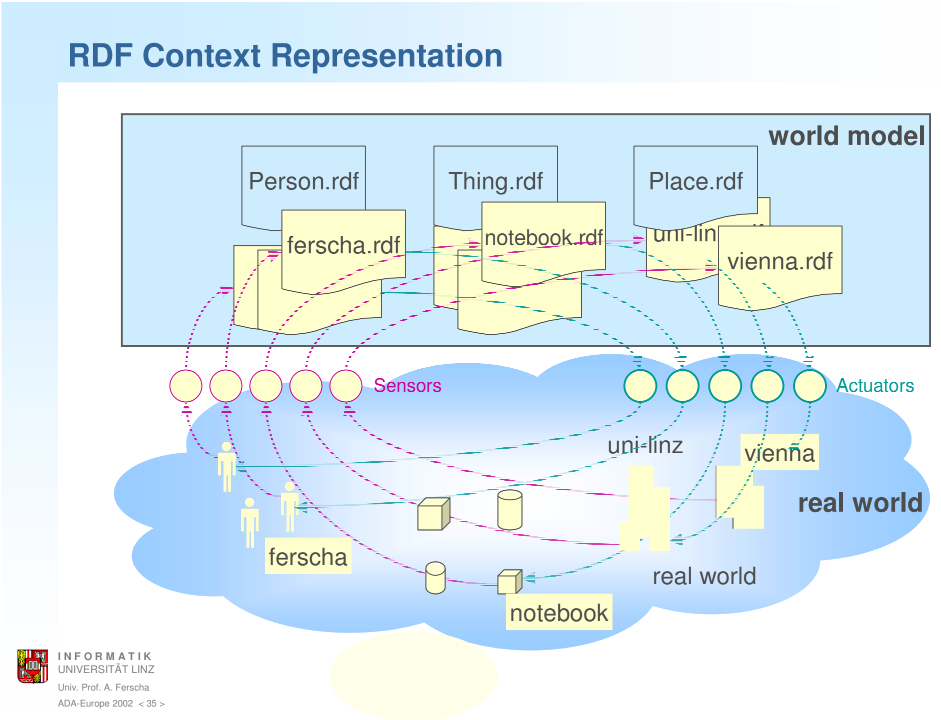
RDF Context Representation
world model
Person.rdf
Thing.rdf
Place.rdf
ferscha.rdf
notebook.rdf
uni-lin
vienna.rdf
Sensors
Actuators
uni-linz
vienna
real world
ferscha
real world
notebook
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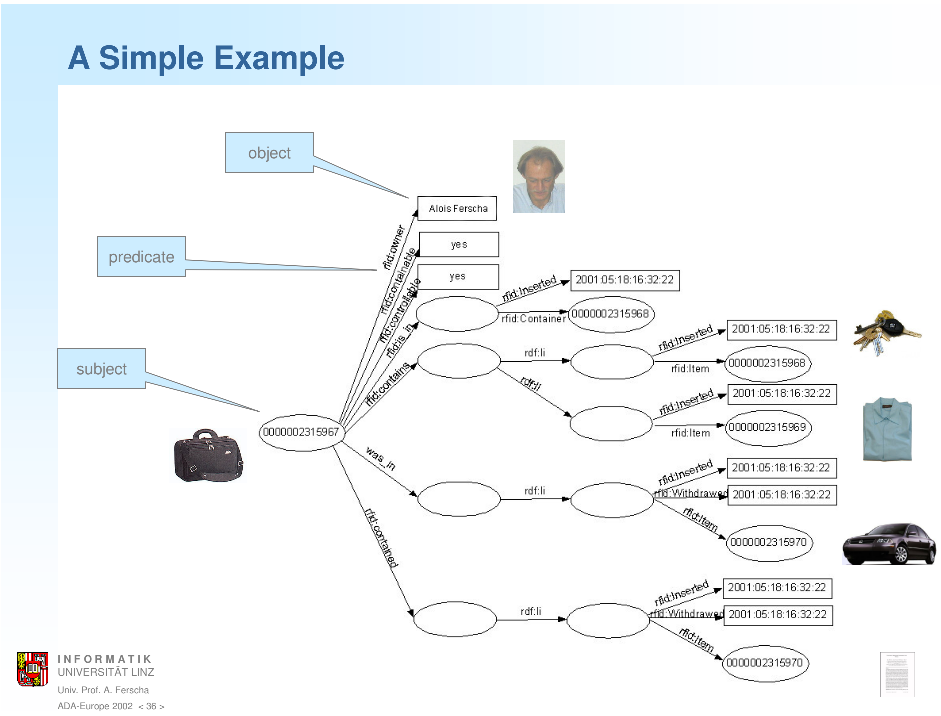
A Simple Example
object
predicate
subject
Alois Ferscha
yes
yes
rfid:owner
rfid:containable
rfid:controllable
rfid:is_in
rfid:contains
was_in
rfid:contained
0000002315967
rfid:Inserted
2001:05:18:16:32:22
rfid:Container
0000002315968
rdf:li
rfid:Item
0000002315969
0000002315970
rfid:Withdrawed
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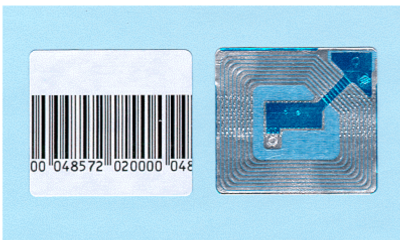
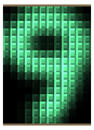
Contextware Challenges

what?	Identification
where?	Localization
how?	Coordination
whereby?	New I/O Technologies

Identification



Identification

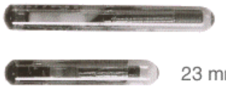


Optical Character Recognition

Barcode-Systems

Biometrical Systems

ID cards



RFID-Systems

01.0000A89.00016F.000169DC0

Header 0–7 bits | EPC Manager 8–35 bits | Object Class 36–59 bits | Serial Number 60–95 bits

Universal Product Code

140 . 78 . 95 . 111

IP Address

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How Many Things? IDs?

Cars (delivered per year)	6.0×10^{6}	23 bit
Computers (in use)	5.6×10^{8}	29 bit
Mobile Phones (in use)	1.1×10^{9}	30 bit
Humans (total)	6.0×10^{9}	33 bit
Grains of Rice (per year)	1.3×10^{16}	54 bit
Water Molecules (on planet)	7.5×10^{45}	152 bit

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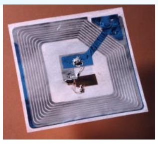
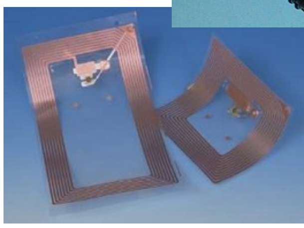
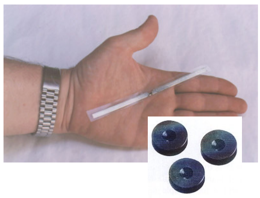
RFID Identification

- „invisibly“ wearable
- trigger actions by physical presence
- act as awareness indicators (presence and/or identification)
- read / writeable transponders

- selected application areas
  - EAS (Electronic Article Surveillance)
  - automatic toll-paying
  - monitoring postal services
  - school/hospital laundry
  - transport / logistics







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Identification

Example: IC with HF Transponder:

- 2mm x 2mm x 10 µm
- 1m wireless energy supply
- conductable ink antenna
- 512 Byte ROM/RAM

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Identification

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[www.autoidcenter.org 2002]

Identification: Ambient Intelligence

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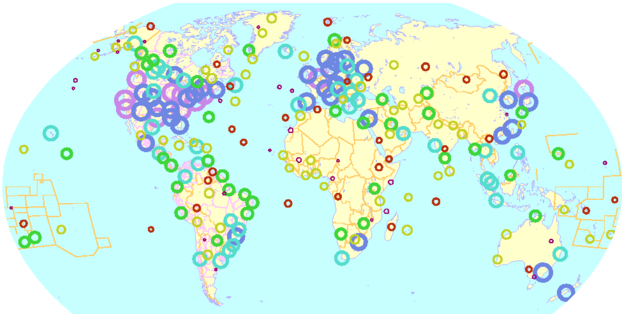
Localization



Localization: Principles

Containment: check whether object is contained / inside

Positioning: determine current physical location (of user / device / thing)

Absolute	vs.	**Relative**
Self	vs.	**Remote**
Tagged	vs.	**Untagged**
Outdoor	vs.	**Indoor**
(e.g. GPS-based)		(e.g. infrared sensors, short-range radios)

- geometric relationship among users / devices can be accurately described with knowledge of location information

Localization Systems (Positioning)

Active Localization: send signal to localize target

Cooperative Localiz.: target cooperates with the system

Passive Localization: deduce from observation of signals “already present”

Blind Localization: deduce location of target without *a priori* knowledge

Active Mechanisms

Non-cooperative
- System emits signal, deduces target location from distortions in signal returns
  e.g. radar and reflective sonar systems

Cooperative Target
- Target emits a signal with known characteristics; system deduces location by detecting signal
  e.g. ORL Active Bat, GALORE Panel, AHLoS

Cooperative Infrastructure
- Elements of infrastructure emit signals; target deduces location from detection of signals (e.g. GPS, MIT Cricket)

Passive Mechanisms

Passive Target Localization
- Signals normally emitted by the target are detected (e.g. birdcall)
- Several nodes detect candidate events and cooperate to localize it by cross-correlation

Passive Self-Localization
- A single node estimates distance to a set of beacons (e.g. 802.11 bases in RADAR [Bahl et al.], Ricochet in Bulusu et al.)

Blind Localization
- Passive localization without a priori knowledge of target characteristics
- Acoustic “blind beamforming” (Yao et al.)

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Positioning with GPS

Indicates 39 degrees, 43 minutes, 17 seconds north longitude; 105 degrees, 1 minute, 26 seconds west latitude.

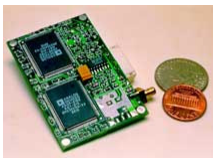
GPS

Example Casio Pathfinder
- Receiver frequency 1575.42MHz
- Tracking 8 satellites1 sec update rate
- Measurement accuracy: 30m
- Display screens: Current position, Map plot, Graphical navigation, Way point plot
- Battery life: 720

- GPS in PCMCIA, Chipcard

dGPS
- Measurement accuracy: 50 cm (reference station fixed)
- phase difference method: 1 cm
- Galileo (new in Europe)

Street Pilot
(GIS Mapping)



NAV2K GPS Kit

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Localization Systems

Technology	Technique	Physical	Symbolic	Absolute	Relative	LLC	Recognition	Accuracy and precision if available	Scale	Cost	Limitations
GPS	Radio time-of-flight lateration	•		•		✓		1-5 meters (95-99 percent)	24 satellites worldwide	Expensive infrastructure $100 receivers	Not indoors
Active Badges	Diffuse infrared cellular proximity		•	•			✓	Room size	1 base per room, badge per base per 10 sec	Administration costs, cheap tags and bases	Sunlight and fluorescent light interfere with infrared
Active Bats	Ultrasound time-of-flight lateration	•		•			✓	9 cm (95 percent)	1 base per 10 square meters, 25 computations per room per sec	Administration costs, cheap tags and sensors	Required ceiling sensor grid
MotionStar	Scene analysis, lateration	•		•			✓	1 mm, 1 ms, 0.1° (nearly 100 percent)	Controller per scene, 108 sensors per scene	Controlled scenes, expensive hardware	Control unit tether, precise installation
VHF Omni-directional Ranging	Angulation	•		•		✓		1° radial (≈ 100 percent)	Several transmitters per metropolitan area	Expensive infrastructure, inexpensive aircraft receivers	30-140 nautical miles, line of sight
Cricket	Proximity, lateration		•	∘	∘	✓		4 × 4 ft. regions (≈ 100 percent)	≈ 1 beacon per 16 square ft.	$10 beacons and receivers	No central management receiver computation
MSR RADAR	802.11 RF scene analysis and triangulation	•		•			✓	3-4.3 m (50 percent)	3 bases per floor	802.11 network installation, ≈ $100 wireless NICs	Wireless NICs required
PinPoint 3D-iD	RF lateration	•		•			✓	1-3 m	Several bases per building	Infrastructure installation, expensive hardware	Proprietary, 802.11 interference

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[Hightower, Borriello 2001]

Localization Systems

Avalanche Transceivers	Radio signal strength proximity	•			•			Variable, 60-80 meter range	1 transceiver per person	≈ $200 per transceiver	Short radio range, unwanted signal attenuation
Easy Living	Vision, triangulation		•	•			✓	Variable	3 cameras per small room	Processing power, installation cameras	Ubiquitous public cameras
Smart Floor	Physical contact proximity	•		•			✓	Spacing of pressure sensors (100 percent)	Complete sensor grid per floor	Installation of sensor grid, creation of footfall training dataset	Recognition may not scale to large populations
Automatic ID systems	Proximity		•	∘	∘		✓	Range of sensing phenomenon (RFID typically <1m)	Sensor per location	Installation, variable hardware costs	Must know sensor locations
Wireless Andrew	802.11 proximity		•	•			✓	802.11 cell size, (≈ approx. 100 m indoor, 1 km free space)	Many bases per campus	802.11 deployment, ≈ $100 wireless NICs	Wireless NICs required, RF cell geometries
E911	Triangulation	•		•			✓	150-300 m (95 percent)	Density of cellular infrastructure	Upgrading phone hardware or cell infrastructure	Only where cell coverage exists
SpotON	Ad hoc lateration	•			•		✓	Depends on cluster size	Cluster at least 2 tags	$30 per tag, no infrastructure	Attenuation less accurate than time-of-flight

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[Hightower, Borriello 2001]

Coordination

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Coordintation Definitions

[Carriereo/Gelernter 90]
„Coordination is the process of building programs by gluing together active pieces“

[Singh 92]
„Coordination is the integration and harmonious adjustment of individual work efforts towards the accomplishment of a larger goal“

[Malone 94]
„Coordination is the act of managing dependencies between activities“

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Coordination

A coordination model is a triple (E,M,L):

- E are the coordinable entities:
  the active agents which are coordinated, the building blocks of a coordination architecture
  (agents, processes, tuples, atoms, ...)

- M are the coordinating media:
  media enabling the coordination of interagent entities; serve to aggregate a set of agents to form a configuration
  (channels, shared variables, tuple spaces, bags, ...)

- L are the coordination laws:
  ruling actions by coordination entities
  (associative access, guards, synchr. constraints ...)

Linda Coordination

Formal Specification of Linda

E	Types:	Type = {int, char, ...}
	typ. Values:	Value = $\cup\{a : \tau, \bot : \tau \mid \alpha \in V\,\tau\}$
	pass. Tupel:	Tuple = Value^{i}
	akt. Tupel:	Active = (Value $\cup$ Process)^{i}
	Operators:	Op = {eval(t) $\mid t \in$ Active} $\cup$ {out(s), rd(s), in(s) $\mid s \in$ Tuple
	Processes:	Process::= Γp,
	Tuple Space:	TS = $\oplus\{t : \#\,[t]\}$
M	Tuple Space:	Linda < Γ, $\rightarrow$ > where Γ = TS and $\rightarrow \subseteq$ TS $\times$ TS
L	process generation:	$\forall t \in$ Active: $\{t'[i : \text{eval}(t).e]\} \rightarrow \{t'[i : e], t\}$
	Tuple generation:	$\forall t \in$ Tuple: $\{t'[i : \text{out}(t).p]\} \rightarrow \{t'[i : p], t\}$
	Tuple copying:	$\forall s,t \in$ match: $\{t'[i : \text{rd}(s).p]\ t\} \rightarrow \{t'[i : t.p], t\}$
	Tuple deletion:	$\forall s,t \in$ match: $\{t'[i : \text{in}(s).p]\ t\} \rightarrow \{t'[i : t.p]\}$
	local transition	$\dfrac{p' \rightarrow p''}{\{t'[i : p']\} \rightarrow \{t''[i : p'']\}}$ $\dfrac{ts' \rightarrow ts''}{ts \oplus ts' \rightarrow ts \oplus ts''}$

GAMMA Coordination

General **A**bstract **M**odel for **M**ultiset m**A**nipulation [Banatre, LeMetayer 90]

Data structure: multiset (bag)
Control structure: Γ operator (fixed-point operator)

$\Gamma((R_1, A_1), \ldots, (R_m, A_m))\quad (M) =$
if $\forall i \in [1,m], \forall x_1, \ldots, x_n \in M, \sim R_i(x_1, \ldots, x_n)$
then M
else **let** $x_1, \ldots, x_n \in M$
let $i \in [1,m]$ **such that** $R_i(x_1, \ldots, x_n)$ **in**
$\Gamma((R_1, A_1), \ldots, (R_m, A_M))\quad ((M - \{x_1, \ldots, x_n\}) + A_i(x_1, \ldots, x_n))$

$M, \{\ldots\}$ … multisets
R_i, A_i … reaction function (no global variables)
(replace in M a subset of elements $\{x_1, \ldots, x_n\}$, s.t. $R_i(x_1, \ldots, x_n)$ for the elements $A_i(x_1, \ldots, x_n)$ holds.

→ all possible reactions are fired

action

condition

Example: `sieve: x, y → y ⇐ multiplicity_of(x,y)`

GAMMA Programming Schemes (Tropes)

operational behaviour of the model is strictly implicit

- programmer does not specify any order of execution which is by default completely parallel
- BUT: practical use of it reveals that a number of program schemes can be identified which are the ones most often used by programs

- **Transmuter:** same operation applied to all elements
  $$T(C,f) \equiv x \rightarrow f(x) \Leftarrow C(x)$$
- **Reducer:** operation applied to pairs of elements that meet condition (reduces size of multiset)
  $$R(C,f) \equiv x,y \rightarrow f(x,y) \Leftarrow C(x,y)$$
- **Optimiser:** optimises multiset while preserving its structure
  $$O(<,f1,f2,S) \equiv x,y \rightarrow f1(x,y),f2(x,y) \Leftarrow ((f1(x,y),f2(x,y)) < x,y)$$
  and $S(x,y)$ and $S(f1(x,y),f2(x,y))$
- **Expander:** decomposes multiset into set of basic values
  $$E(C,f1,f2) \equiv x \rightarrow f1(x), f2(x) \Leftarrow C(x)$$
- **Selector:** filter removing elements satisfying certain condition
  $$Sij(C) \equiv x1, \ldots, xi \rightarrow xj, \ldots, xi \Leftarrow C(x1, \ldots, xi) \text{ mit } 1 < j \leq i+1$$

Nonstandard I/O Technologies

Contextware Challenges

Contextware

Devices
- Heterogeneity
- Mobility
- Limited Ressources
- Seamless Connectivity
- Sensors
- Actuators
- Smart Things, Places ..

Users and Interfaces
- Natural Interaction
- Universal Interfaces
- Multimodality
- Intelligence & Smartness
- Proactivity
- Nonobtrusive
- Invisible
- Adaptation

Software
- Context-awareness
- Mobility & distribution
- Service Announcement and Discovery
- Adaptation
- Dynamic interoperability
- Component discovery
- Rapid development
- Rapid deployment
- Scalability

Real Life Problems

"... Real life problems are those that remain after you have systematically failed to apply all the known solutions."

Edsger Dijkstra, 1973

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