"... 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
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

- Embedded Computers: 80%
- Vehicles: 12%
- Interactive Computers: 2%
- Robots: 6%
- Fixed Infrastructure: 10%
- Servers: 20%

150M per year
8000M parts/year

Observation 3: Mobile Communication

Convergence of Standards, Information and Communication

Cellular Standards
- SW Radio
- Multi-standard
- GSM/UMTS
- GSM/IS2000
- GSM/IS136
- EDGE
- GSM

Past
- Multi-standard
- Multimedia
- Picture Phone
- Consumer phone
- Budget Phone
- Business Phone
- Picture Phone
- PIC/PDA
- Multimedia Terminal

Future
- Multi-standard
- Multimedia
- Picture Phone
- Consumer phone
- Budget Phone
- Business Phone
- Picture Phone
- PIC/PDA
- Multimedia Terminal

2G: 9.6 Kbps
Research: 1982
Rollout: 1992

2.5G: 115Kbps
384 Kbps

3G: 2Mbps
Research: 1992
Rollout: 2001

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Observation 4: Wireless Communication

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

Observation 5: Seamless Access

Single (optical) Fiber: 10 Gb/s
Wavelength Multiplexing: 20 Tb/s

PLC outdoor: 12 MHz, 350m, 2 Mb/s
PLC in-house: 15-30 MHz, 70m, 10 Mb/s
Observation 6: Internet

Qualitative Growth: Embedded Internet

- Mobility of Devices, Users, Services
  (E-Commerce ⇒ M-Commerce)

- Networked Embedded Systems
  - Smart Things
  - Smart Spaces

- Wireless Sensors / Actuators

---

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[CAIDA 2001]
Observation: Embedded Internet

Tiny Web Server

Dallas Semiconductors Web Server

HYDRA Web Server (Xerox PARC)

Web Servers on a Chip

Example: Embedded Internet

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

- in almost all **Everyday Objects**

- **Wireless** Interconnect

- **Continuous** Connectivity
Example: Embedded Internet

Vision: A world where...

... bits and atoms are merged
... physical objects interact in real time
... all the time
... everything is aware of everything
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]

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
Context

- system is "aware" of physical, social etc. environment (states, events history, causalities, etc.)
- explicit I/O is monopolising 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

Implicit I/O
Explicit I/O

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

Event driven
Time driven

Context-Transformation

Context-Rules

Implicit trigger
Explicit trigger
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

Sensor Technologies

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

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

Optical/Acoustical 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, Knowledge Representation, ...
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

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
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]
1: $\text{istrue}(p, c)$ proposition $p$ is true in some context $c$

Attardi’s notion of context [Attardi 93]
1: $\text{in}(s; \text{vp})$ statement $s$ can be entailed from the viewpoint $\text{vp}$

Chiunchiglia’s notion of Context [Chiunchiglia et. al 90, 93]
1: belief contexts for multi-agent theories
2: context-based framework for mental representation

Context Representation: (Recent Approaches)

Key-value pairs [Schilit 93]
1: environment variable acting as the key, value of the variable holding the actual context data (e.g.: Mobisaic [Voelker et.al 94])

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

Object-oriented model
1: based on the concept of integrating an active-object model with a hypertext information model
2: 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
1: 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
The “Person – Place – Thing” Approach

Context Representation: A Metadata Approach

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

Structure
<table>
<thead>
<tr>
<th>Resource</th>
<th>(subject)</th>
<th><a href="http://www.soft.uni-linz.ac.at/~suitcase">http://www.soft.uni-linz.ac.at/~suitcase</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>Property</td>
<td>(predicate)</td>
<td><a href="http://www.schema.org/#owned">http://www.schema.org/#owned</a></td>
</tr>
<tr>
<td>Value</td>
<td>(object)</td>
<td>“Alois Ferscha”</td>
</tr>
</tbody>
</table>

Representation as directed graph

```
http://www.soft.uni-linz.ac.at/~suitcase \( s:owned \) Alois Ferscha
```

Univ. Prof. Alois Ferscha
(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

RDF Context Representation

real world

fenersch
is_owner

is_in

uni-linz

vienna

contains

contains

notebook
RDF Context Representation

RDF Context Representation

Person.rdf  Thing.rdf  Place.rdf
RDF Context Representation

A Simple Example
Contextware Challenges

what? Identification
where? Localization
how? Coordination
whereby? New I/O Technologies
How Many Things? IDs?

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

Identification

Example: IC with HF Transponder:
- 2mm x 2mm x 10 μm
- 1m wireless energy supply
- conductable ink antenna
- 512 Byte ROM/RAM

<contains>
ATS!100!Y379397Q
ATS!100!Y387877F
ATS!50!DF79230Y
€!20!676876888
...

<valuta>
ATS 3.456,00
€ 256,89
US$ 110.25
...
Identification:

Ambient Intelligence

[www.autoidcenter.org 2002]
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 Localization:** 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.)

Positioning with GPS

**GPS**
- Example Casio Pathfinder
  - Receiver frequency 1575.42MHz
  - Tracking 8 satellites 1 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)
### Localization Systems

<table>
<thead>
<tr>
<th>Technology</th>
<th>Technique</th>
<th>Physical</th>
<th>Symbolic</th>
<th>Absolute</th>
<th>Relative</th>
<th>LLC</th>
<th>Recognition</th>
<th>Accuracy and precision &amp; scale</th>
<th>Cost</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>Radio-based signal triangulation</td>
<td>*</td>
<td>*</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>1-5 meters (80-95 percent)</td>
<td>Expensive</td>
<td>Line-of-sight</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>24 satellites worldwide</td>
<td>$100 receivers</td>
<td>Not indoors</td>
</tr>
<tr>
<td>Active Tags</td>
<td>Diffusion in plane or plane</td>
<td>*</td>
<td>*</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Radio waves, 100 meters per second</td>
<td>Administrative costs, up to 100 tags per second</td>
<td>Sunlight and transmission errors not visible</td>
</tr>
<tr>
<td>Active Tags</td>
<td>Diffusion in volume</td>
<td>*</td>
<td>*</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Transmission loss</td>
<td>Administrative costs, up to 100 tags per second</td>
<td>Sunlight and transmission errors not visible</td>
</tr>
<tr>
<td>MicroBeacon</td>
<td>Time-of-flight</td>
<td>*</td>
<td>*</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Sound waves, 100 meters per second</td>
<td>Central control, requires precise installation</td>
<td>Central control, requires precise installation</td>
</tr>
<tr>
<td></td>
<td>Angle of arrival</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sound waves, 100 meters per second</td>
<td>Central control, requires precise installation</td>
<td>Central control, requires precise installation</td>
</tr>
<tr>
<td></td>
<td>Indoor</td>
<td>*</td>
<td>*</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Sound waves, 100 meters per second</td>
<td>Central control, requires precise installation</td>
<td>Central control, requires precise installation</td>
</tr>
<tr>
<td>NIF</td>
<td>Single frequency</td>
<td>*</td>
<td>*</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Sound waves, 100 meters per second</td>
<td>Central control, requires precise installation</td>
<td>Central control, requires precise installation</td>
</tr>
<tr>
<td></td>
<td>Indoor</td>
<td>*</td>
<td>*</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Sound waves, 100 meters per second</td>
<td>Central control, requires precise installation</td>
<td>Central control, requires precise installation</td>
</tr>
<tr>
<td></td>
<td>Indoor</td>
<td>*</td>
<td>*</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Sound waves, 100 meters per second</td>
<td>Central control, requires precise installation</td>
<td>Central control, requires precise installation</td>
</tr>
<tr>
<td></td>
<td>Indoor</td>
<td>*</td>
<td>*</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Sound waves, 100 meters per second</td>
<td>Central control, requires precise installation</td>
<td>Central control, requires precise installation</td>
</tr>
</tbody>
</table>

**Localization Systems**

- **Active Tags**: Diffusion in plane or plane with radio waves, 100 meters per second.
- **Data Link**: Indoor communication with sound waves, 100 meters per second.
- **MicroBeacon**: Time-of-flight with sound waves, 100 meters per second.
- **NIF**: Single frequency with sound waves, 100 meters per second.

**Key Features**

- **GPS**: 1-5 meters accuracy with 24 satellites.
- **Active Tags**: Radio waves, 100 meters per second.
- **MicroBeacon**: Sound waves, 100 meters per second.
- **NIF**: Single frequency with sound waves, 100 meters per second.

**Cost Considerations**

- **GPS**: Expensive receivers, $100 per unit.
- **Active Tags**: Administrative costs, up to 100 tags per second.
- **MicroBeacon**: Central control, requires precise installation.
- **NIF**: Central control, requires precise installation.

**Limitations**

- **GPS**: Not indoors.
- **Active Tags**: Sunlight and transmission errors not visible.
- **MicroBeacon**: Central control, requires precise installation.
- **NIF**: Central control, requires precise installation.

---

[Hightower, Borriello 2001]
Coordination

Coordination Definitions

[Carriero/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“
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 = \{a: \tau, \bot: \tau | \alpha \in \mathcal{V} \}\ |
|   | pass. Tupel: Tupel = Value |
|   | akt. Tupel: Active = (Value \cup Process)^i |
|   | Operators: Op = \{eval(i) | i \in Active\} \cup \{out(s), rd(s), in(s) | s \in Tuple\} |
| Process: | Process ::= \Gamma p |
| Tuple Space: | TS = \oplus \{t: \# \}\ |
| M | Tuple Space: Linda < \Gamma, \rightarrow > where \Gamma = TS and \rightarrow \subseteq TS \times TS |
| L | process generation: \forall t \in Active: [t[i : eval(i).e]] \rightarrow [t[i : e], t] |
|   | Tuple generation: \forall t \in Tupel: [t[i : out(i).p]] \rightarrow [t[i : p], t] |
|   | Tuple copying: \forall s.t \in match: [t[i : rd(s).p]] \rightarrow [t[i : t.p], t] |
|   | Tuple deletion: \forall s.t \in match: [t[i : in(s).p]] \rightarrow [t[i : t.p]] |
|   | local transition: \begin{array}{c}
p' \rightarrow p^* \\
\hline
\text{ts} \rightarrow \text{ts}^* \\
\hline
\end{array} \\
\leftarrow [t[i : p]] \rightarrow [t'[i : p'], t] \quad ts \oplus ts' \rightarrow ts \oplus ts' |
GAMMA Coordination

General Abstract Model for Multiset Manipulation [Banatre, LeMetayer 90]

Data structure: multiset (bag)
Control structure: \( \Gamma \) operator (fixed-point operator)
\[
\Gamma((R_1, A_1), \ldots, (R_m, A_m)) (M) = \\
\text{if } \forall i \in [1,m], \forall x_1, \ldots, x_n \in M, \neg R_i(x_1, \ldots, x_n) \\
\text{then } M \\
\text{else let } x_1, \ldots, x_n \in M \\
\text{let } i \in [1,m] \text{ such that } R_i(x_1, \ldots, x_n) \in M, \ldots \text{ multisets} \\
R_i, A_i \ldots \text{ reaction function (no global variables)} \\
(M - \{x_1, \ldots, x_n\}) + A_i(x_1, \ldots, x_n)
\]

→ all possible reactions are fired

Example: sieve: \( x, y \rightarrow y \iff \text{multiplicity of}(x,y) \)

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
  \( T(C,f) \equiv x \rightarrow f(x) \Leftrightarrow C(x) \)

- Reducer: operation applied to pairs of elements that meet condition
  (reduces size of multiset)
  \( R(C,f) \equiv x,y \rightarrow f(x,y) \Leftrightarrow C(x,y) \)

- Optimiser: optimises multiset while preserving its structure
  \( O(<,f1,f2,S) \equiv x,y \rightarrow f1(x,y),f2(x,y) \Leftrightarrow ((f1(x,y),f2(x,y)) < x,y) \)
  and \( S(x,y) \) and \( S(f1(x,y),f2(x,y)) \)

- Expander: decomposes multiset into set of basic values
  \( E(C,f1,f2) \equiv x \rightarrow f1(x), f2(x) \Leftrightarrow C(x) \)

- Selector: filter removing elements satisfying certain condition
  \( S_{ij}(C) \equiv x_1, \ldots, x_i \rightarrow x_{j}, \ldots, x_i \Leftrightarrow C(x_1, \ldots, x_i) \text{ mit } 1 < j \leq i+1 \)
Nonstandard I/O Technologies

Contextware Challenges

- **Devices**
  - Heterogeneity
  - Mobility
  - Limited Resources
  - 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