Everyobjects in the Pervasive Computing Landscape

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The Disappearing Computer

“The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.”


Ubiquitous Computing (since 1988, Weiser):
computers massively deployed, pervasive, calm

“each person is continually interacting with hundreds of nearby interconnected computers without explicitly attending to them”
Communication :: Growth …
926,201 IP addresses, 2,000,796 IP links, 865,000 destinations, 50% of globally routable network prefixes; www.caida.org, UC Regents 2006

1.086,250.903
Communication :: Growth and Shrinking

Tiny Web Server

HYDRA Web Server (Xerox PARC)

Web Servers on a Chip

Bluetooth
Networks of Things

- **invisible processors**, lightweight, cheap, low/no power
- in almost all everyday objects
- wirelessly interconnected, continually "online"

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SmartCase
[Ferscha 2001]
Pervasive Computing

Empowering people with a “pervasive computing landscape” that is:

- aware of their presence
- sensitive, adaptive and responsive to the users capabilities, needs, habits and emotions
- and ubiquitously, safely and securely accessible
- via natural interaction
“Everyobjects” in the Pervasive Computing Landscape

Sensors — Actuators

from other

to other

Entity

Entity

Entity

Entity

from other
to other

Sensors — Actuators

Sensors — Actuators

Sensors — Actuators
Pervasive Computing = Special Purpose Computing

The Post-PC Era: Giving up on Universal Computing

- Computing in the **background** (embedded, networked, situated ...)
- Dedicated tools and devices ("made for purpose")
- **Multimodal** input and output (pen, touch, voice, gesture,..)
- Provide a close fit with real need of users
- Pre-configured for lifetime / zero maintenance
- **Specialization in function, focus upon a single activity**
The Essence of the Information Appliance

"To me, the primary motivation behind the information appliance is clear: simplicity. Design the tool to fit the task so well that the tool becomes a part of the task, feeling like a natural extension of the person. This is the essence of the information appliance."


Three Axioms for Information Appliances:

**Simplicity:** the complexity of the appliance is that of the task, not the tool. The technology is invisible.

**Versatility:** Appliances are designed to allow and encourage novel, creative interaction.

**Pleasurability:** Products should be pleasurable, fun!
Information Appliances

Universal Remote Control
[Ferscha et. al. 2005]

Gestural Interaction
[Ferscha et. al. 2005]
The 1st Epoch: **Connected**

An emerging pervasive/ubiquitous computing landscape:
miniaturized / cheap / fast / powerful / (wirelessly) connected / “always on”

- miniaturization / explosive growth:
  computing, storage, communication/bandwidth, embedded technologies

- omnipresent / total connectivity:
  zillions of embedded chips: spontaneous, situational interaction

- special purpose computing / information appliances:
  computers as secondary artefact

- sensor-actuator systems: (also: human-out-of-the-loop)
  sensors collect data, passive interaction with environment
  actuators control devices, can modify environment

**Challenge:**
(i) objects / artefacts not “aware” of themselves / each other
(ii) lack of context
Pervasive Communications = Contextual Communications

The Post-IP Era: Giving up on Centralized // Global Communications

- Communicate and be communicated with everywhere // “here and now”
- Spatial / temporal communication // interaction // coordination contexts
- Multi-lateral communication // interaction // coordination “goal tribes”
- Context-aware self-description and self-configuration of autonomous artefacts for the purpose of communication among the “unbeknown”
- Disconnected clouds of societal artefacts communicating intelligently
- Communication // interaction // coordination in spatial proximity
Context Sensors

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, Konwledge Representation, ...

GPS (SiRFIIl GPS Engine Board)
- SiRF Star III Chipset
- Very high sensitivity (Tracking Sensitivity: -159dBm)
- Built-in patch antenna
- Position: 10 meters, 2D RMS
- 5 meters, 2D RMS, WAAS enabled
- Velocity: 0.1 m/s
- Time: 1 us synchronized to GPS time

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

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

Blood gas sensor (IMEC, 2002)
Sensor Dust (UC Berkeley, 2002)

Bluetooth
- RF 2.4GHz, FHSS
- ~ 1Mbit/s
- 0/20 dBm Power
- 0-10/100 m
Context Awareness

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

[Sensors]

- event driven
- time driven

[Context-Transformation]

Context-Rules
- implicit trigger
- explicit trigger

[Actuators]

[Ferscha 2003]
Towards Self-* Artefacts / Objects

Ability to Self-describe

- Physical properties (e.g. weight, energy, ID, processing power, …)
- Capabilities (e.g. services, keys, …)
- Interests (goals, preferences, addiction …)
- Context (geoposition, location, orientation, speed, nearby artefacts, …)

Adaptation to Context

- Filter / adapt self-description wrt. to different situations

Embedded self-contained behaviour/functionality

- Behaviour / functionality encoded into the self-description of the artefact

Further issues

- Uniform structure and content of the self-description (semistr. XML-document, cf. Physical Markup Language)
- Enable linking of artefacts (e.g. to perform a single task)
- Self-descriptions of groups of artefacts (e.g. new capabilities)
- Cope with different representation of the same type of data

Ability to Self-manage

To enable autonomy, artefacts have to manage themselves

- Artefacts should operate without central control and as little human intervention as possible
- Process controlling the behaviour of the artefact (what does artefact, what causes it to do something, …)

Rule-based process control

- A set of rules controls the “life-cycle” of an artefact
- Rules can change dynamically (e.g. context-dependent)

Interaction between artefacts is based on

- proximity (spatial, focal, temporal, causal, …) or
- locality (e.g. geographic addressing)

(Dynamically) plug code in life-cycle of artefact

- Discovery of and communication with other artefacts
- Control sensors and actuators
- Execute self-contained behaviour/functionality from self-description of artefacts

Ability to Self-organize

Composition of artefacts // configuration of ensembles

- artefact heterogeneity // complementary competencies
- goal oriented ensemble formation / configuration
- artefacts can serve as a proxy for other artefacts (e.g. limitd resources, power, etc.)

Multilateral interaction within artefact ensembles

- match interests encoded in self-description of multiple artefacts (semantic interoperability)
- goal negotiation in case of conflicts

Reasoning about ensembles of artefacts („goal tribes“)

- exploit semantic meaning of relationships
- orchestrated cooperation
- mechanisms of coordination
- „ensemble intelligence“
Spontaneous Context Aware Interaction

Aura

1 a : a *subtle sensory stimulus*  
   b : a distinctive *atmosphere surrounding a given source*

2 : a *luminous radiation*

3 : a *subjective sensation* (as of lights) experienced before an attack of some disorders (as epilepsy or a migraine)

4 : an *energy field* that is held to emanate from a living being

<Meriam-Webster Online 2006>
Spontaneous Aware Interaction :: The Digital Aura Approach

Paradigm for spontaneous interaction:
- individual
- spontaneous / ad-hoc
- context-sensitive
- spatial proximity
- similarity of interest

Methodological approach:
- Profile of interests / preferences (XML)
- proximity sensing (BT, IrDA, WiFi, ..)
- “en-passant” profile exchange
- profile matching / similarity detection
- active / passive „Privacy Control“

Bluetooth
- RF 2.4 GHz, FHSS
- 0-10 / 100 m @ < 0.7 Mbit/s
- 0/20 dBm

WLAN ad hoc
- RF 2.4 GHz, FHSS, DSSS
- 30 – 100 m @ < 11 Mbit/s
- 20dBm

RFID
- 1cm – 6m
- Active vs. Passive Transponder

IrDA
- „Line of Sight“
- 0-3 / 5 m @ < 4, 0.115 Mbit/s
Spontaneous Aware Interaction: Layered Architecture

Peer interaction in a layered architecture
1. PeerLayer initiates communication using the TransportLayer
2. A peer is located/identified (received by TransportLayer, handed over to PeerLayer)
3. Connection is established; Profile Layer is notified
4. Two step matching process is initiated: i) role profile ii) interest profile
5.1 role profiles exchanged among peers
5.2 in case of matching roles → exchange of (contextualized) interest profiles among peers (containing only data corresponding to matching roles)
5.3 interest profiles are transcoded wrt. context
5.4 interest profiles are matched against (local) interest specifications
6 matching algorithm returns similarity value [0..1]
   if similarity hits (application specification) threshold → application is triggered
7 application starts executing
Hierarchical Symbolic Context Model (CCAtoms, CCAggregates)

time: 2002.05.23; 13:11:12
space: 100° 20” 25“

"work": time: 8:00 – 23:00
space: "Physikgebäude P111"
Hierarchical Symbolic Context Model (CCAtoms, CCAggregates)

**CCAtom** is a single, indivisible point (basic item) in context space
symbolizes finest granularity context (limited e.g. by sensor resolution)

**CCAggregates** allows to define more complex subspaces of the context space
Using of geometrical set operations, such as Union, Intersection, Negation, etc.
Wildcards and logical constructors (with no restrictions to depth of nesting)
Context Verification: geometrical subspace inclusion problem

<CCAggregate id=Montpellier>
  <Place>
    <From coordinates=39°54'32''/>
    <To coordinates=39°54'36''/>
  </Place>
</CCAggregate>

<CCAggregate id=DOA06>
  <Time>
    <From time=30,10,2006/15,45,00/>
    <To time=01,11,2006/17,30,00/>
  </Time>
</CCAggregate>

<CCAggregate id=OTMconferences06>
  <intersect>
    <CCAggregate id=Montpellier>
    <CCAggregate id=DOA06>
  </intersect>
</CCAggregate>
Similarity Analysis of Profiles

similarity / dissimilarity metrics:
- normalised distance function:
  \[ \delta(o_i, o_j) = 1 - d(o_i, o_j) \] with
  - \( d(i,j) \geq 0 \)
  - \( d(i,i) = 0 \)
  - \( d(i,j) = d(j,i) \)
  - \( d(i,j) \leq d(i,k) + d(k,j) \)
- \textit{E.g. Minkowski distance}:
  with \( i = (x_{i_1}, x_{i_2}, \ldots, x_{i_p}) \) and \( j = (x_{j_1}, x_{j_2}, \ldots, x_{j_p}) \) as two \( p \)-dimensional data objects
  \[ d(i,j) = \sqrt[p]{(|x_{i_1} - x_{j_1}|^q + |x_{i_2} - x_{j_2}|^q + \ldots + |x_{i_p} - x_{j_p}|^q)} \]

Problem: types of variables
- Interval scale (temperature, height, ..)
- Binary (yes/no, on/off, ..)
- Nominal scale (Leymann, Katz, Ferscha, ..)
- Ordinal scale (excellent, good, poor, ..)
- Ratio-scaled (Growth of Bacteria: \( A e^{Bt} \), ..)
- Semi structured data (XML, ..)

Problem: global similarity and single variable similarity
Problem: “similar enough” difficult to define (subjective)
“adducent” extremes
Digital Aura :: Context Aware / Implicit / Spontaneous Interaction
Digital Aura :: Context Aware / Implicit / Spontaneous Interaction
Context based Privacy Control

“Passive” Privacy Control:
- Selectively accepting incoming profile information

“Active” Privacy Control:
- Selectively disseminate personal profile information

“Filter strength” adaptive to context!

Mondays, 13:00 – 17:00
when in the Campus Cafeteria

Fridays, 18:00 – 22:00
while on the train
Digital Aura  ::  Context based Privacy Control
The 2nd Epoch: Connected >> Aware

Spontaneous Interaction based on ability to selfdescribe, -manage, -organize. Focus on context acquisition / representation / exploitation to steer application

- artefacts / objects interacting in spontaneous spatial / temporal contexts based on proximity, priority, privileges, capabilities, interests, offerings, environmental conditions, etc.

- opportunistic interactions: based on local goals and objectives defined as policies / rules / constraints

- coincidental coordination: among the “unbeknown” “Peer-to-Peer” communication paradigm / “shared nothing” paradigm

Challenge: (i) uncertainty, future situations (ii) no common knowledge / understanding / plan
Future Awareness

the ability of a system to foresee its near or far future and the future of its environment respectively

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 Prediction

Context Triggering
implicit / explicit event triggering

Controlling Actuators
control the environment

[Ferscha 2003]
Future Awareness: Context Prediction

Feature Extraction

Context Classification

Context Prediction

Sensors
- EMG on the masseter muscle in microvolts
- Skin conductance waveform (in micro-Siemens)
- Heart rate (in beats per minute)
- Respiration waveform (in % expansion)

pattern recognition

Clustering:
- Partitioning
- Hierarchical
- Density-based
- Grid-based
- Model-based

averaging
- Smoothing
- ANN
- SOMs
- Bayesian FC
- HMM
- SVM
- ARMA / ARIMA

...
Methods for Context Prediction

Classification (supervised learning)

Goal: Predict class $C_i = f(x_1, x_2, .. x_n)$

- Regression
- Decision trees
- Bayesian Classification
  - Naive Bayesian Classification
  - Bayesian Belief Networks
- Neural Networks
  - Classification by Backpropagation
- Nearest neighbor
- Radial basis functions
- Support vector machines
- Case-based reasoning
- Genetic algorithm
- Rough set approach
- Fuzzy set approaches
- Meta learning methods
  - Bagging, boosting

Clustering (unsupervised learning)

Goal: group set of data

maximizing intra-class similarity and
minimizing inter-class similarity

class labels of training data are unknown
aim in finding possibly existing classes
or clusters in the data

- Hierarchical methods
  - Top-down (starts with all the objects in the same cluster)
  - Bottom-up (starts with each object forming a separate cluster)
- Model-Based Clustering Methods
  - Neural Networks, Self-Organizing Maps (SOM)
- Density-Based Methods
  - a neighborhood has to contain at least a minimum number of points (density threshold)
- Grid-Based Methods
  - It quantizes the object space into a finite number of cells that form a grid structure
Context Prediction

History-based Context Prediction

reactive strategy: determine context at time t based on [t-n, t], context knowledge is processed at time t+\(\Delta\) but might be outdated

proactive strategy: forecast context at time t+\(\Delta\) based on [t-n, t]
Context Prediction: ARIMA Characterisation of Context Sequence

- Consider the arrival process as an unknown stochastic process \( \{X_i\} = (X_1, X_2, ..., X_n) \)
- \( X_i = \delta_i - \delta \) empirically observed timestamp differences transformed by the series mean \( \delta \)
- Model \( \{X_i\} \) by ARMA\([p,q]\), defined as

\[
X_t = \sum_{i=1}^{p} \phi_i X_{t-i} + \varepsilon_t + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i}
\]

i.e. composition of
- a pure autoregressive process of order \( p \) (AR\([p]\)) explaining \( X_t \) as a dependency

\[
X_t = \phi_1 X_{t-1} + \phi_2 X_{t-2} + ... + \phi_p X_{t-p} + \varepsilon_t
\]

\( \varepsilon_t \) being white noise random error, and
- a pure moving average process of order \( q \) (MA\([q]\)) that explains \( X_t \) as a series of IID white noise errors

\[
X_t = \varepsilon_t + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + ... + \theta_q \varepsilon_{t-q}
\]

with \( \text{E}(\varepsilon_i) = 0, \text{Var}(\varepsilon_i) = \sigma^2_e \) and \( \text{E}(X_t)=0 \).
Context Prediction: Automated Characterisation of ARIMA[$p,d,q$]

**Stationarity:** after d-fold differencing the series

**Order Identification:**
pure AR[$p$]: order approximated from empirical partial autocorrelations $r_{k-1}(k)$
pure MA[$q$]: order approximated from autocorrelations $r(k)$
combined ARMA[$p,q$] process: order approximated by $(p,q)$ that minimizes

$$AIC(p,q) = \log \sigma^2_{p,q} + \frac{2}{n}(p+q)$$

**Parameter Estimation:**
$(\phi_1,...,\phi_p,\theta_1,...,\theta_q)$ are determined as MLE, i.e. choose estimates that minimize the square sum

$$S^2(\hat{\phi}_1,...,\hat{\phi}_p,\hat{\theta}_1,...,\hat{\theta}_q) = \sum_{t=\infty}^{n} \tilde{e}_t^2$$

of the residuals $\tilde{e}_t = \delta_t - \hat{\phi}_1\delta_{t-1} - ... - \hat{\phi}_p\delta_{t-p} - \hat{\theta}_1\epsilon_{t-1} - ... - \hat{\theta}_q\epsilon_{t-q}$

**Diagnostics / Verification:**
Portmanteau lack-of-fit-test at confidence level $(1-\alpha)$
(quantifies the „trust“ in the forecast)

**Forecast:**
recursively (Durbin-Levinson) generate the k-step best linear prediction

ARIMA(3,0,0)
Forecast Based on ARIMA Model

Durbin-Levinson 5-Step Best Linear Forecast
(based on ARIMA[3,0,0])

Further Approaches: Statistical Learning Theory

- learning from examples, online algorithms
- complexity vs. prediction accuracy
- Support Vector Machines, Principal Component Analysis
Pro-Active Artefacts / Objects

- environment aware
  - by monitoring environment and own behaviour
  - develop an implicit model of the environment

- self adaptive
  - control decisions exclusively
  - established based on local information

- pro-active
  - control decisions based on anticipated future world states – triggered at the right time for the right state
Common Knowledge / Understanding / Plan

Vision: „Stick-on Intelligence“

„everything connected“: interaction / coordination cannot be organised centrally. Complexity of different / optimised / flexible processes becomes unmanageable.

Peer-It: Concept

**Peer-it:** open, modular, extensible, scalable, stick-on, all-in-one sensor/actuator-communication platform

**Sensors:** measuring signals (optical, acoustic, electronic, chemical, physical, magnetic, …)

**Actuators:** component at the parent part of a closed loop controlled system

**Communication:** wired / wireless communication technology

**Hardware:** processor, identification, wireless communication, proximity sensors, …

**Software:** P2P architecture, component technology, software reuse, …

**Standards:** IEEE 802.11, IEEE 802.15, OSGi, …
Peer-It: Proof of Concept

**Peer-It:**

PC104/+ Board: „SECO M570„ (90x96mm)
„Via Eden“ x86 compatible CPU: 300 Mhz - 1 Ghz; PCI / ISA Bus (PC104/+ connector)
64 MB RAM, 128 MB nonvolatile memory (Compact-Flash)
2x USB 1.1; 10/100 Mbit Ethernet; 1x parallel port, 2x serial port
Audio port dual channel, MIC, LINE-OUT
Integrated 3D graphics controller
VGA / Keyboard / Mouse connector
Typical power consumption: 7,5 W @ 400 MHZ
Debian GNU/Linux 3.0 Woody
Adjusted 2.4.26 Kernel,
Adjusted boot system, read-only operating system
Easy to manage, configure and update
(FAT fileysystem with linux as image-file, xml configuration from windows)
„Blackdown“ Java 1.3.1

**Sensors:**
Inside RFID Reader („PicoTag Family“) for passive RFID Tags @ 13,56MHz
Tag storage capacity: 640 Bit or 2KByte

**Actuators:**
2 Serial Ports (Operation modi:RS-232, RS-422 or RS-485)
1 parallel Port (Operation modi: SPP, ECP, EPP)
2 USB 1.1 Ports

**Comm.:**
10/100 Mbit Ethernet
IEEE 802.11b via USB-WLAN Stick (Netgear MA111)
IEEE 802.15 Bluetooth 1.1 Class 2 (20 meters) USB Dongle (Acer BTCSR)
Peer-it Scenario: FMS
Peer-it Scenario: FMS
Peer-It Demonstrator: Autonomic Manufacturing

**Transport-Peer:** autonomic vehicle to carry products (goods, artefacts, ..)

**Processing-Peer:** operational unit /machinery processing products (artefacts)

**Monitoring-Peer:** monitoring, inspection, supervision of transport and processing peers

**Artefact:** products, goods, ..
Peer-It Demonstrator: Autonomic Manufacturing
The 3rd Epoch:  **Connected >> Aware >> Smart**

Skills for Orientation / Planning / Scheduling / Acting
- Logical Reasoning
- Pattern matching
- Symbolic manipulation

Endorse a self-* Artefacts / Objects paradigm
- Self – describing: intentions / capabilities / requirements for coordination unobtrusively / invisibly / seamlessly embodied in each physical real world artefact
- Self – management: coherently adapt to the self-description of other objects/artefacts
- Self – organizing: situative networks / situative communication semantics

Future Awareness

Possible Approach:  Stick-on Intelligence
(Communications / Sensors / Actuators)
Research Challenges

**Dependable Self-Managing Systems**
- systems that “regulate” themselves wrt. reliability, real-time capabilities, fault tolerance, availability, scalability, security, power constraints, authenticity, …
- embedded systems engineering: provably correct systems, concurrency and distribution, composeability, hierarchy, heterogeneity, resource constraints, non-functional requirements
- software development: formal models and programming abstractions, service-oriented architectures, model-based design, composeable components, proof obligations, development frameworks and middleware, verifyable automatic code generation, failure models and self-stabilization, context / future awareness, “intelligent” behavior, design for reuse, unobtrusive user interaction, verification/validation, secure software
- hardware and system design: low-power, low-cost, low-size designs, mixed signal systems, failure models, secure hardware, fault-tolerant VLSI architectures, dependable SoC, secure wireless devices, dependable wireless sensor networks

**Coordination Models and Frameworks**
- coordination is the act of managing dependencies between activities
- creation/destruction, control of communication flow, spatial distribution, synchronization and distribution of actions and activities over time
- biologically inspired (CHAM, PI, Evolutionary Set Theory, Swarms, Hives, )
Research Challenges

**NG “Peers” / “Agents” / “Swarms” / “Autonomic Elements” / “Self Managed Cells”**

- A: orientation (knowledge) > planning (capabilities) > scheduling (resources) > acting
- AE: monitor > analyze > plan > execute – knowledge – sensor | effector
- SM: policy-based control, intelligent control loop (autonomic manager <> resources)
- autonomy, reactivity, pro-activeness, social ability (Woolridge: strong notion of agency)
- mobility, veracity, benevolence, rationality (weak notion)
- standardized CLs (as compared to Speech Acts, KQML, FIPA ACL)
- dependability threats: collective misbehavior, coordinated attacks, sensorized society

**Consensus, Negotiation and Trustworthiness**

- theoretical foundation / algorithms / protocols to negotiate QoS, service level, priority, availability/provision of resources, price, etc.
- standardize agreements / enforcing and reasoning about agreements
- methods translating agreements into action plans
- consensus finding
- negotiation of trust, reputation, credibility

**Computational Perception**

- knowledge models (open standard )
- multi-sensor fusion
- machine learning, reasoning / planning / controlling
Research Challenges

Semantic Systems

- semantic interoperability: towards a 'metadata-enabled' world
  (trends: Semantic Web, Semantic Grid, RDF, DAML+OIL, OWL etc.)
- semantic content and service description, semantic service discovery / composition
- knowledge and ontology engineering

Interacting with the user things

- policy ("decision-making guide"): goal (achieve most desired state), utility function
- roles and profiles ("preferences and intent"): matching (similarity analysis)
- rules ("steering/restricting behavior"): ECA, implicitly in desired state
- understanding / authoring / managing of roles / profiles / policies / rules
- automated derivation of "meaningful" actions (healing, optimization)
- conflict resolution / rule consistency
- new languages, metaphors, expressive means to enable humans to control pervasive computing landscape sufficiently structured and naturally suited to human psychology/ cognition "robust" to human errors

Example: Economics of Attention