Pervasive Computing: A Grand Challenge

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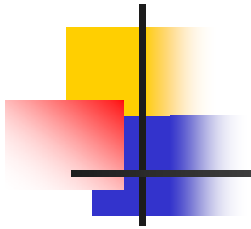

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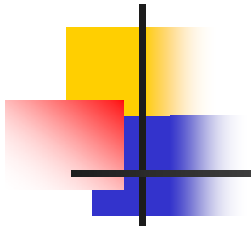
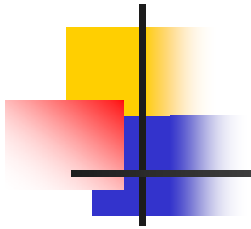
- What is pervasive computing
- Current technology
- Engineering challenges
- Theoretical challenges
- Policy-based autonomic management
- Future activities & conclusions



Grand Challenges

- A long-term challenge for which there is currently no recognised and accepted solution
- Define a 15-20 year project to try to solve the challenge
- Identify clear goals and clear failure criteria
- Encourage world-wide participation
- How to formulate the challenge to be relevant to non-technical public?

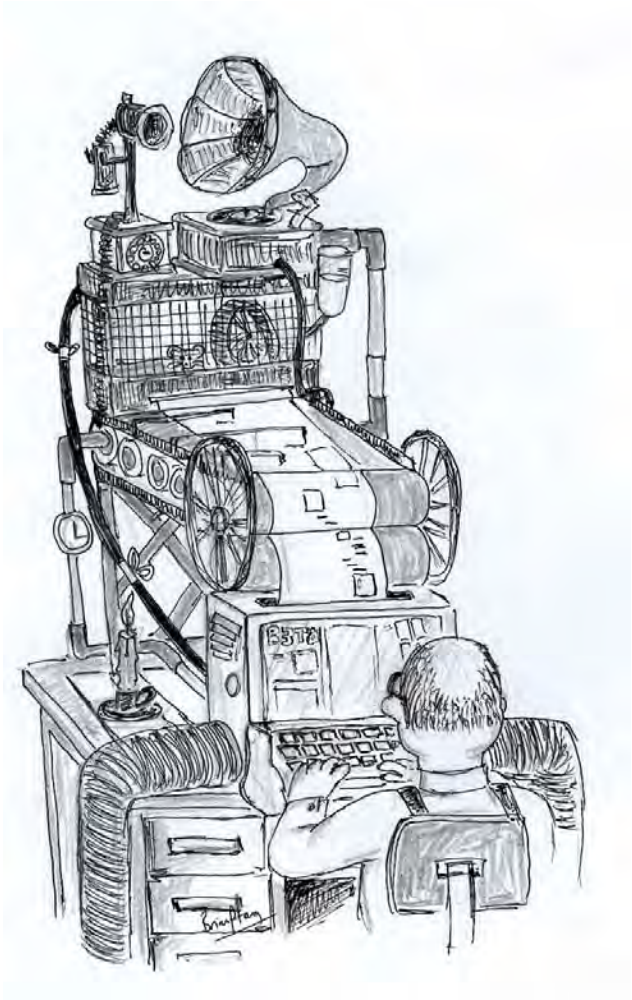


What is Pervasive Computing?

- Technology View
  - Pervasive, Ubiquitous, Sentient
  - Intelligent devices everywhere: home, office, street, car, trains, on-body, implanted, in appliances – 100K devices per person?
  - Mobility of people, environment, and programs
  - Battery powered
  - Capable of wireless communication
- User View
  - Devices mostly invisible – devices interact implicitly with each other and environment
  - Augment human abilities in performance of tasks

☞"The Computer of the 21st Century", Mark Weiser, 1991, Scientific American

The UbiComp Challenge!



- How to build the truly invisible intelligent environment?
- Designed rather than ad-hoc implementation
- Understandable
- Analysable based on underlying theory
- Manageable
- Dependable and secure
- Does not infringe privacy

Need both design and science

Healthcare Everywhere

Applications

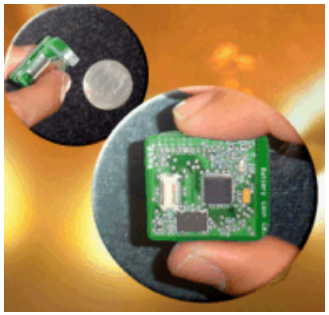
- Automated monitoring
  - Implanted devices
  - Smart clothing
  - Swallow/inject intelligent sensors and actuators
- Health advisor

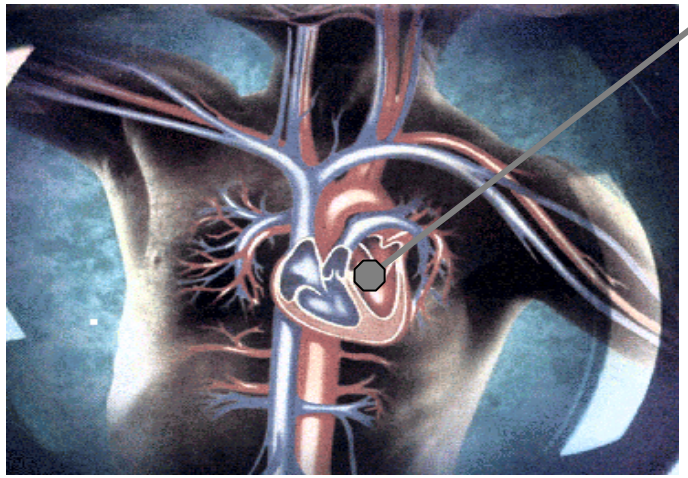
Benefits

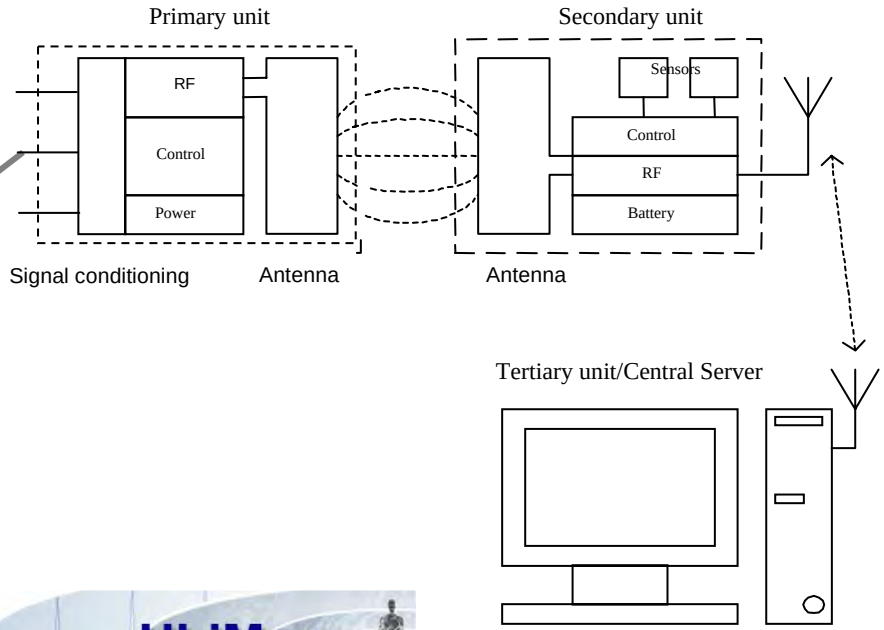
- High ➔lower risk monitoring
- Mobility for chronically ill
- Greater out-of-hospital patient management
- Mass data & analysis
- Emergency feedback or response

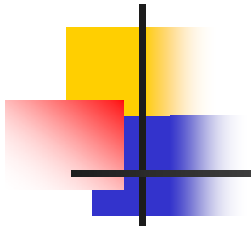
Wireless video camera pill

Cardiac Monitoring



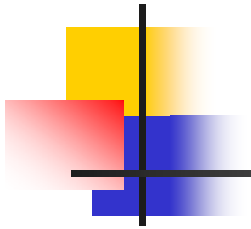






Smart Environments

- Lights, air conditioning, TV automatically switch on and off when you enter or leave rooms
- Sit on your favourite chair and TV switches on to the program you usually watch at this time of the day
- Use communicator/pda for phone, remote control, keys payments, passport, health records, authenticator.
- Route input from ‘virtual’ keyboard to nearest suitable display.
- Automatic detection of new items to control and physical layout in a room or office.



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Current Technology

Wireless PDA/phone

Video phone

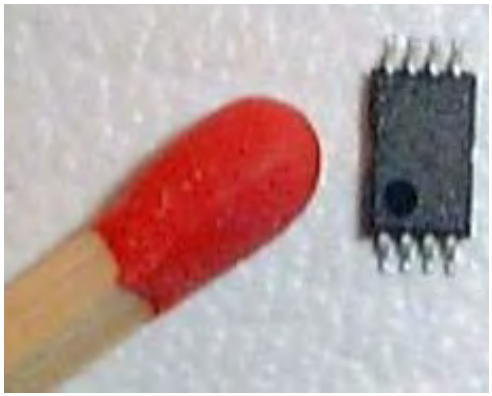
Softphone

www.eleksen.com

Bluetooth Handsfree

Current Technology 2

Matchbox computer

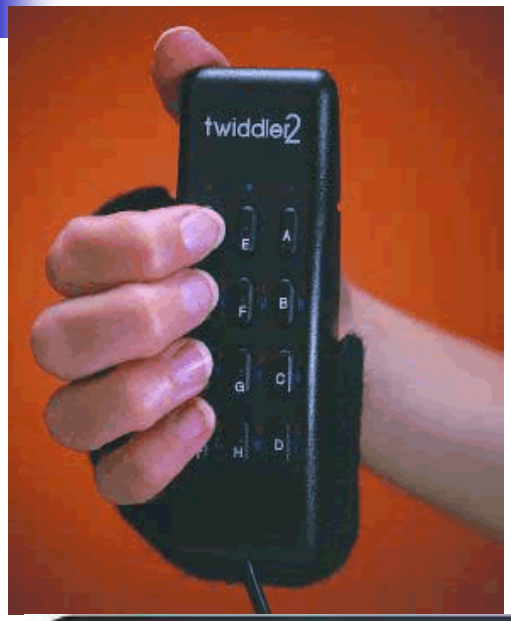


Web Server

Best friend

☞ ***http://matchbox.stanford.edu/cebit.html***
http://www-ccs.cs.umass.edu/~shri/iPic.html

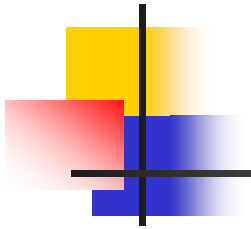
Wearable I/O



LCD Jacket

Wearable I/O

Sony Glasstron

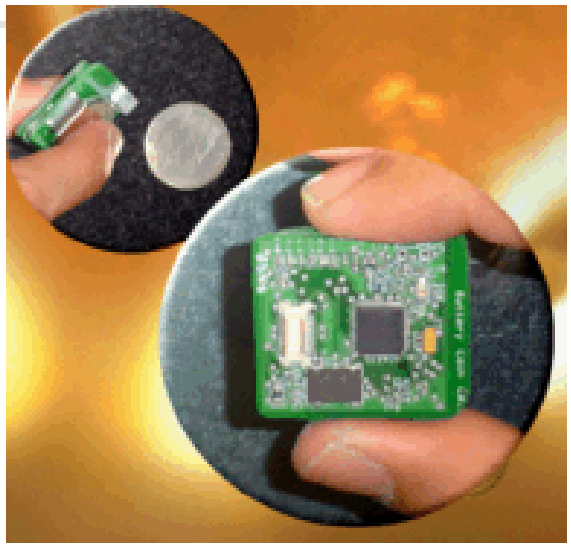


Smart Dust

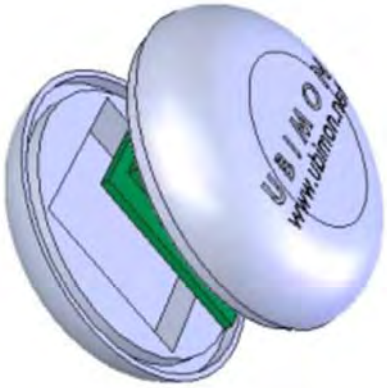
- Autonomous sensing and communication in a cubic millimeter – “dust motes”
- Sensors for temperature, humidity, light, motion .... With bidirectional radio or laser + battery
- Costs soon < $1
- Typical Applications
  - Defence related battlefield sensors, motion detectors etc.
  - Inventory control on boxes which communicate with crates, trucks, plane etc to tell you where they are
  - Product quality monitoring – vibration, humidity, overheating
  - Car component monitoring

☞ *http://robotics.eecs.berkeley.edu/~pister/SmartDust/*

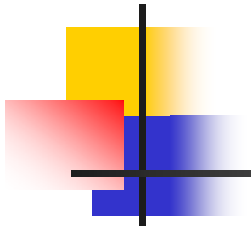
Body Sensor Nodes



- TinyOS
- TI MSP430 ultra low power processor
  - 16 bits RISC processor
  - 64KB +256B Flash memory
  - 12-bit ADC
  - Very low power
- Chipcon CC2420 RF module
  - IEEE 802.15.4 (Zigbee) wireless link
  - 2.4GHz, 250kbps
  - Low current consumption (RX:19.7mA TX:17.4mA)
  - Hardware MAC encryption
  - Range 50m
- 6 analog channels (connect up to 6 sensors)
- 512kByte serial memory

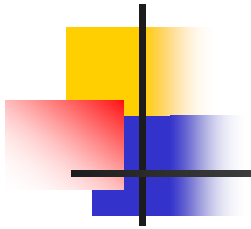


UbiMon
www.ubimon.net



On the Horizon

- Intelligent paper with integrated radio - replace current displays
- Smart paint monitors vibrations and detect intruders or changes colour to react to temperature, lighting etc.
- Intelligent glass can filter sunlight, become opaque - no need for curtains
- Smart garments or injectable sensors for people monitoring
- Printable batteries
  http://www.usatoday.com/life/cyber/tech/review/2001-02-12-batteries.htm
- Etc., Etc.,....



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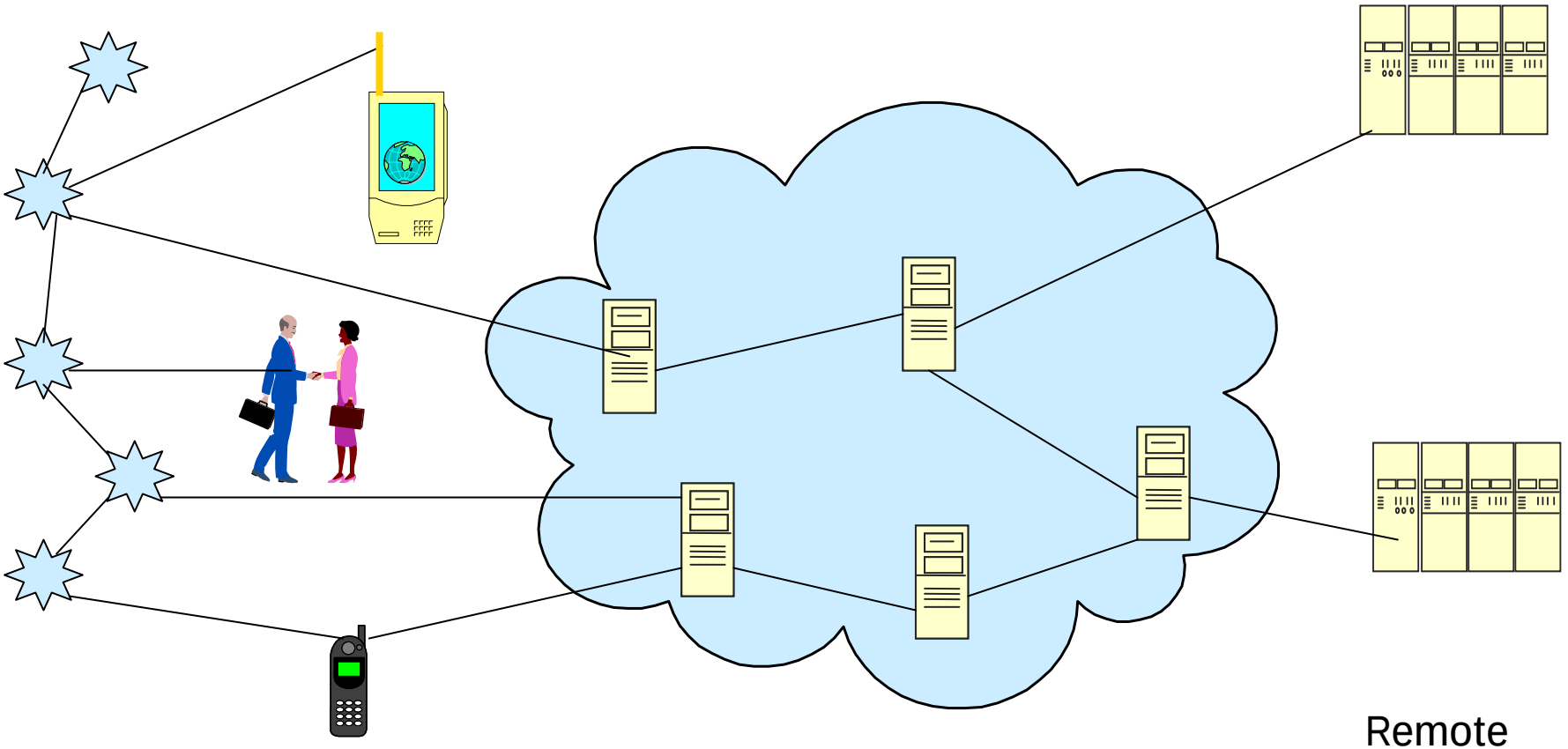
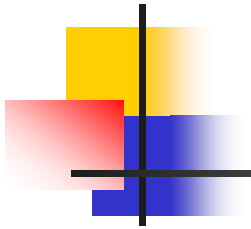
Pervasive Systems Architecture



Power Management

- Require ultra-low power devices, transmitters etc. for body implants, sensor networks
- Light-weight communication protocols
- Sleep mode + low power modes for reduced QoS
- Energy scavenging – extract power from light, heat, vibration or motion
  - Heart motion, solar cells, fuel cells, heat converters,
    heart motion MEMS generators .....

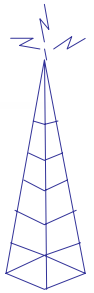
SRI Shoe
Power 0.5W



Context Awareness

- Context defined by:
  - Current location
    Need location detection eg GPS or base station
    Indoors – sonic or ultrawideband wireless tags ➔ 10cm
  - User activity
    Walking, driving a car, running for a bus – how to detect this?
  - Ambient environment
    In theatre, alone, in meeting
  - Device capabilities
    Screen, input, processing power, battery life ….
  - Current QoS availability – particularly for radio links
- Fusion of information from multiple sources

Seamless Communication



- Bandwidth Shortage – reuse techniques
- Heterogeneity
  Zigbee, Bluetooth, GSM/GPRS, 3G,
  IEEE 802.11 a, b & g
- Multimode hardware + seamless handover
- Low power protocol techniques
- Emphasis on IP protocols?

Usability

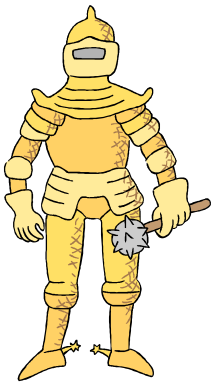
- Common user interface for workstation and mobile device applications
  - Adaptive information display
- Replicate characteristics of paper-based notebooks for annotatability, robustness, universality
- Flexible voice based input+output
  - Voice recognition + text to speech conversion
- Gesture recognition

Information Management

- Billions of sensors generating petabytes of (dynamic) data
- Need filtering, aggregation, collaborative sensing, new query techniques which cater for errors in source.
- Meta data description of information
- Provenance ➔ audit trails, how and where modified etc.

Security Wish List

- Lessons from history: everything worth hacking gets hacked
- SECURITY solutions that are proactive, minimally intrusive, easy to use
- Need for secure ‘out of the box’ set up
- Devices that recognise/respond to “owners” only
- Means of tracing stolen devices, proving transactions
- Ability to be invisible or anonymous when needed
- Protection from spam, viruses, denial of service, identity theft etc.....



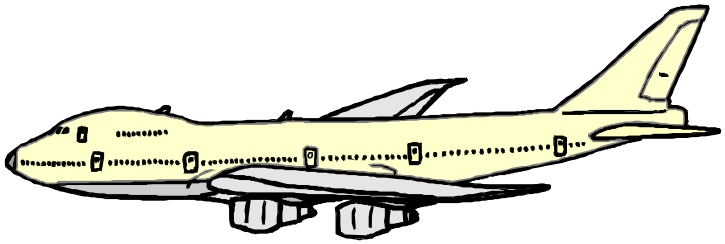
☞ SECURITY solutions that are adaptive and context-aware

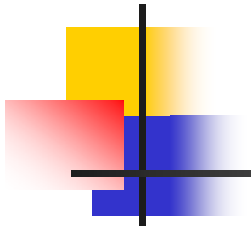
Privacy

- You are now predictable
  - System can co-relate location, context and behaviour patterns
- Do you want employer, colleagues or insurance company to know you carry a medical monitor?
- Tension between authentication and anonymity – business want to authenticate you for financial transactions and to provide ‘personalized’ service
- Users should be aware of being monitored
- Ability to control who/what has access to “my” data (stored, communicated, inferred), ability to define levels of privacy, trust etc

The Business Model

- Who pays for the pervasive support infrastructure of processing, storage, wireless services everywhere:
  on the street, in planes, trains, shops, home?
- Accounting and billing





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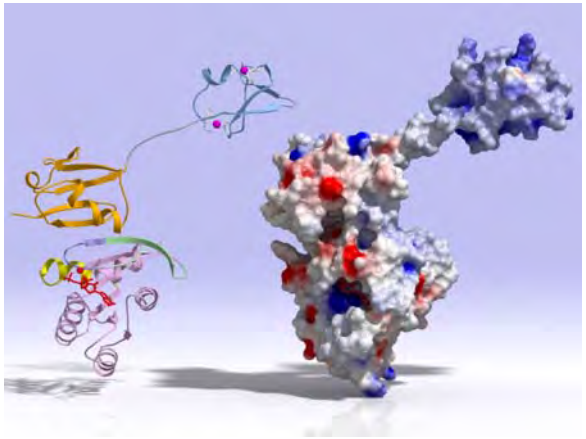
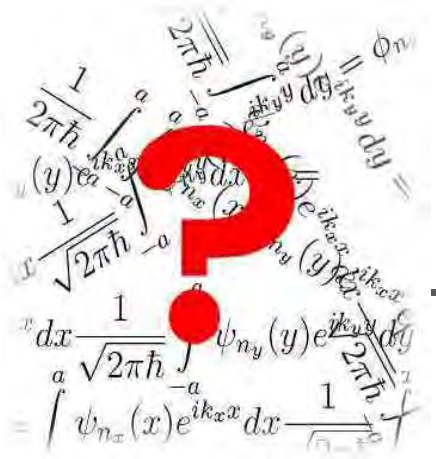
Theory for Pervasive Systems

- We have theory for design and analysis of complex buildings, bridges, electronic circuits

- We need the theory to understand and model complex interactions of pervasive systems

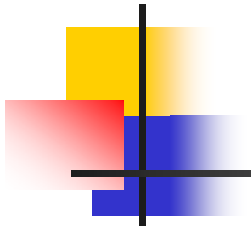


- Currently use ad-hoc implementation, relying on skill of programmers.



Theory Challenges

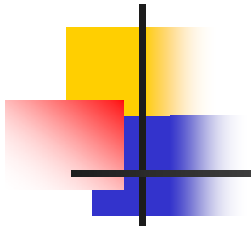
- Large Scale, complex, dynamically self-modifying system, unplanned interactions ...
- To develop an informatic science whose ***concepts***, ***calculi***, ***theories*** and automated tools allow descriptive and predictive analysis of a pervasive system at each level of ***abstraction***
- That every system and software construction - including implementation languages should employ only these concepts and calculi, and be ***analysed*** and ***justified*** by these theories and tools.



Theoretical Foundations

- **Basic notions** Automata; Relational databases; Program logics; Verication; Mathematical semantics; Type theories; . . .
- **Concurrent systems** Petri nets; Process calculi; Logics of action; . . .
- **Ubiquity** Mobility (ambients, pi calculus); Security and privacy; Boundaries, resources and trust; Distributed data; Game-theoretic models; Hybrid systems; Stochastics; Model-checking; . . .

www.cl.cam.ac.uk/users/rm135/plat.pdf



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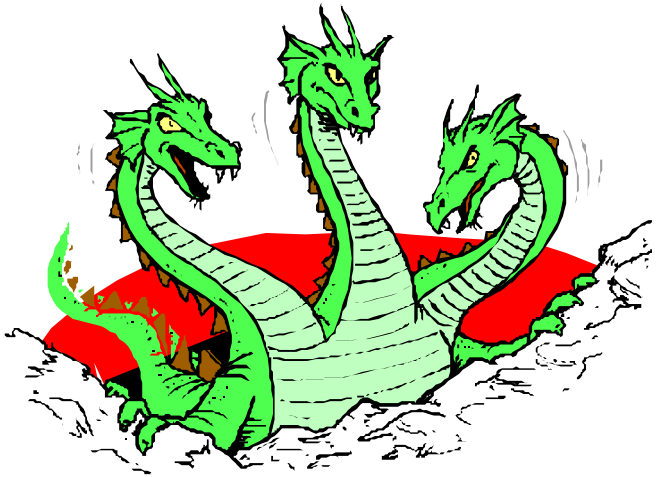
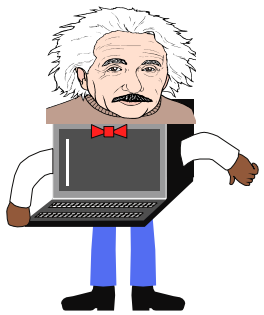
Management – the nightmare!

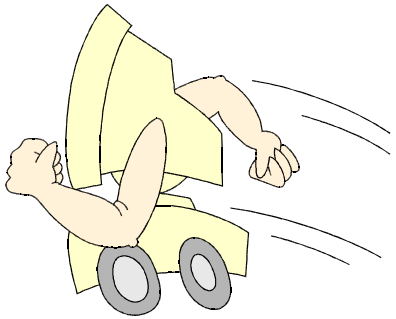


- Huge, complex systems
  - Billions of processors
  - Multiple organisations
  - Managing physical world, controlling sensors, actuators
  - Humans will be in the way
- Hacker and virus paradise
- System propagates false information about individuals or organisation
- Complexity of s/w installation on a workstation or server – how do you cope with billions?
- Cater for huge systems
  + scale down to body area networks

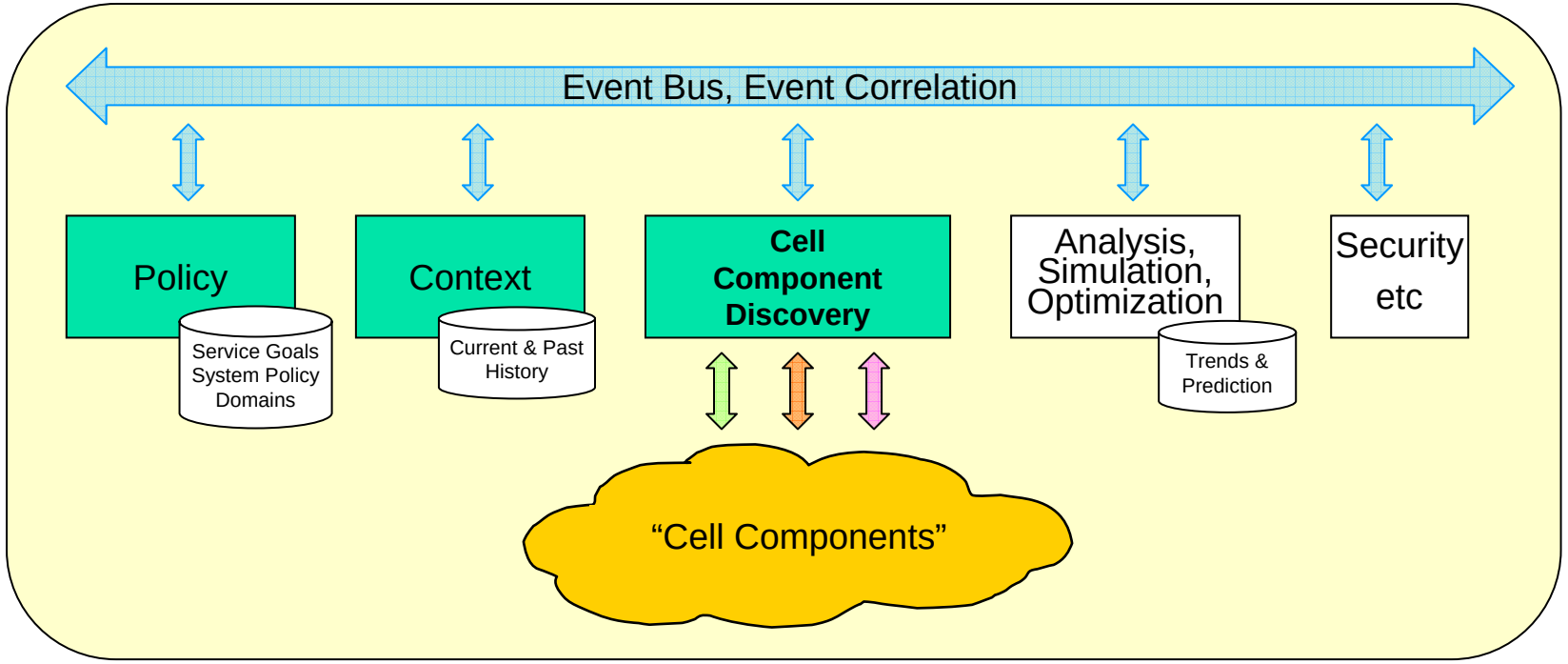
Autonomic Management

- **Autonomic** – self-organising, self-configuring, self-healing, self-optimising, adaptive management
- Remove human from the loop
- Intelligent agents, mobile agents, policy, genetic algorithms?

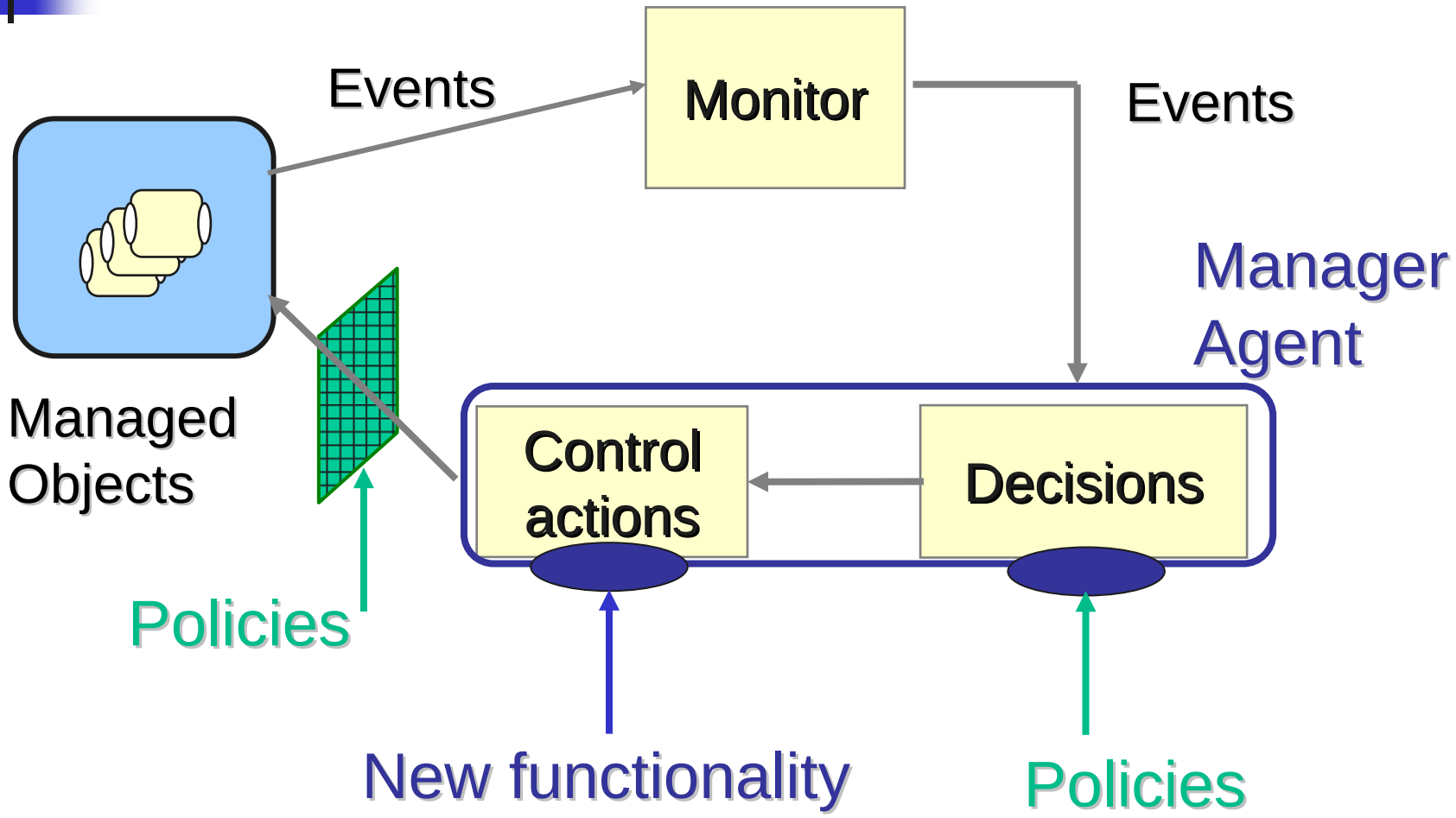




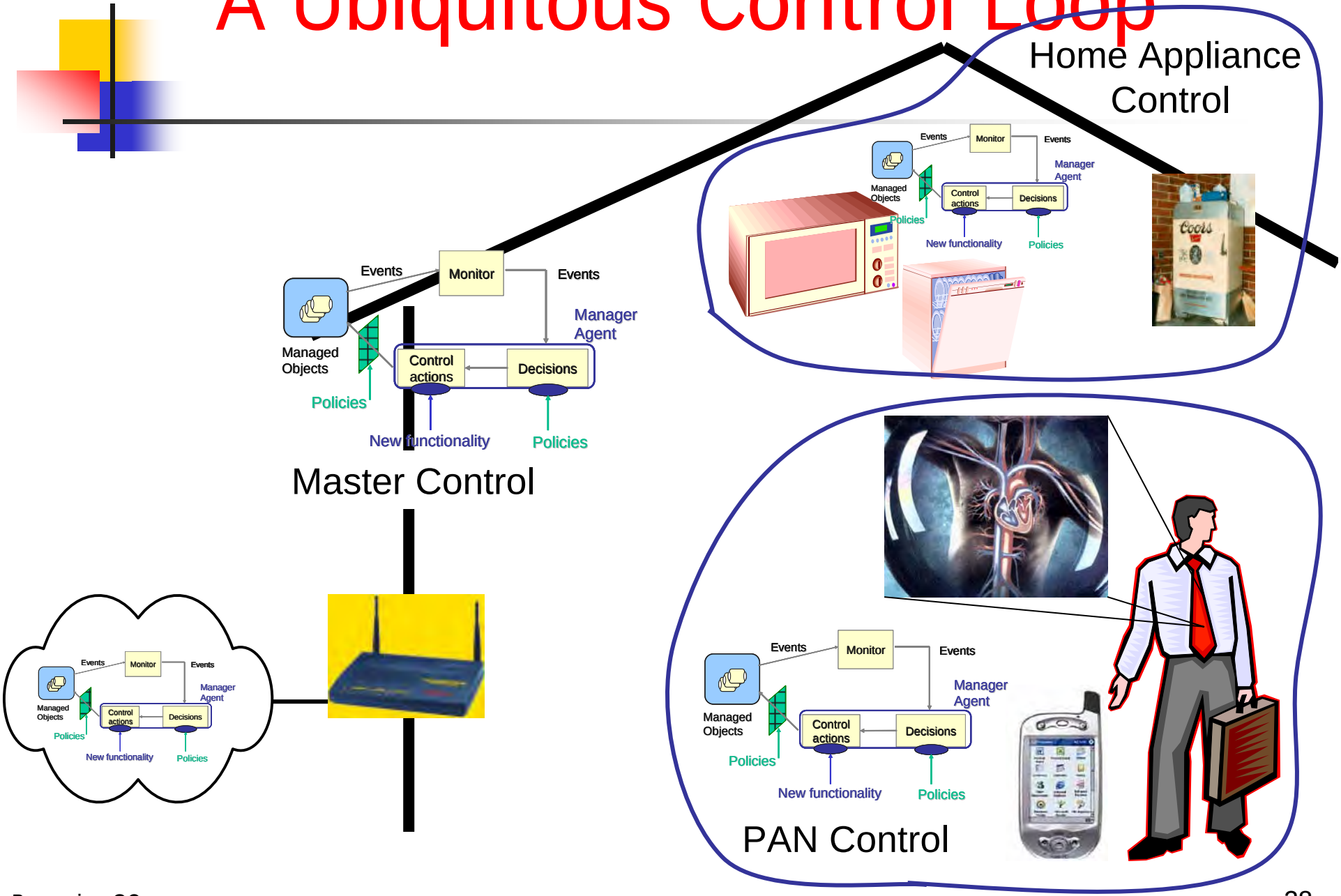
Self-Managed Cell (SMC)



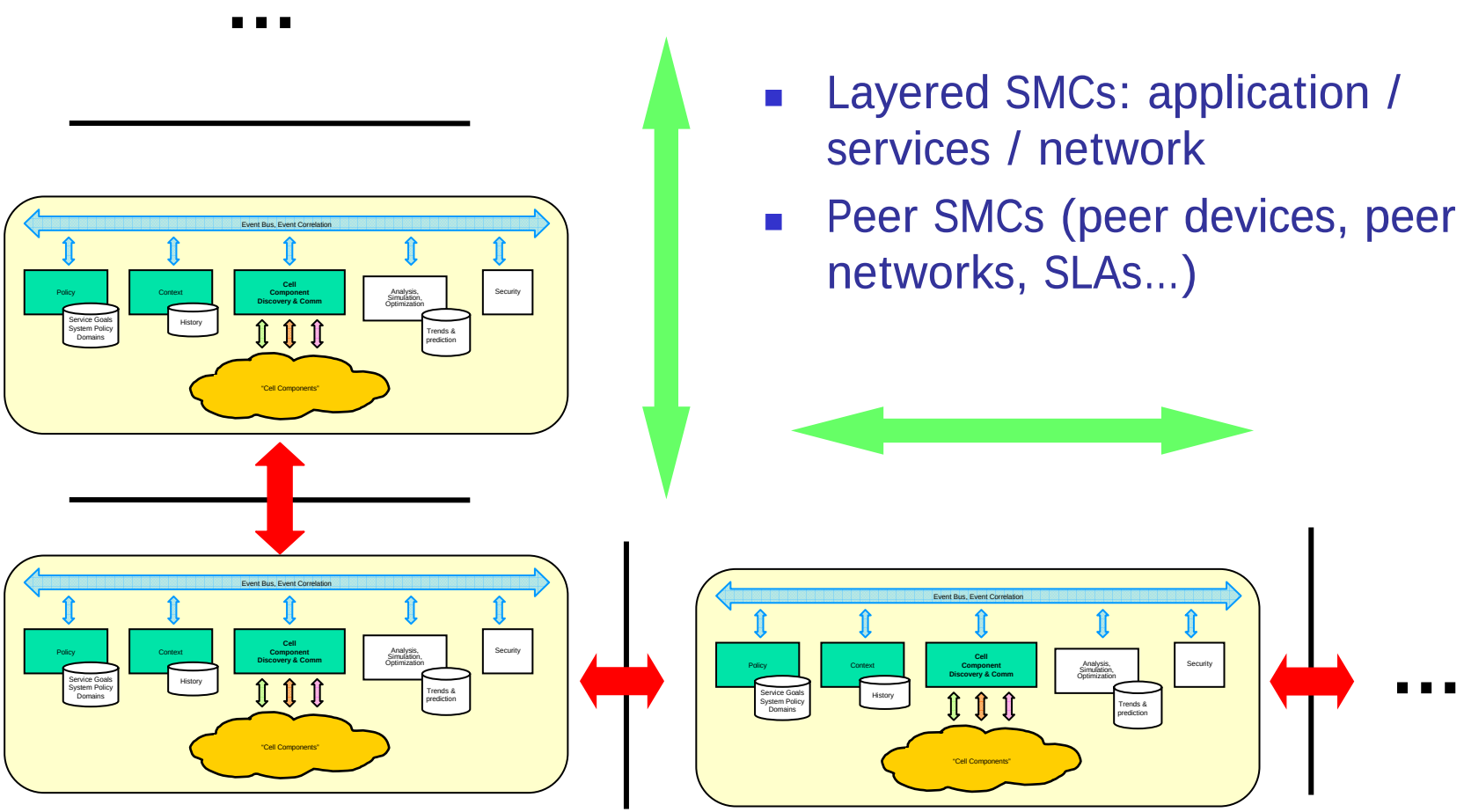
Policy-Based Management



A Ubiquitous Control Loop

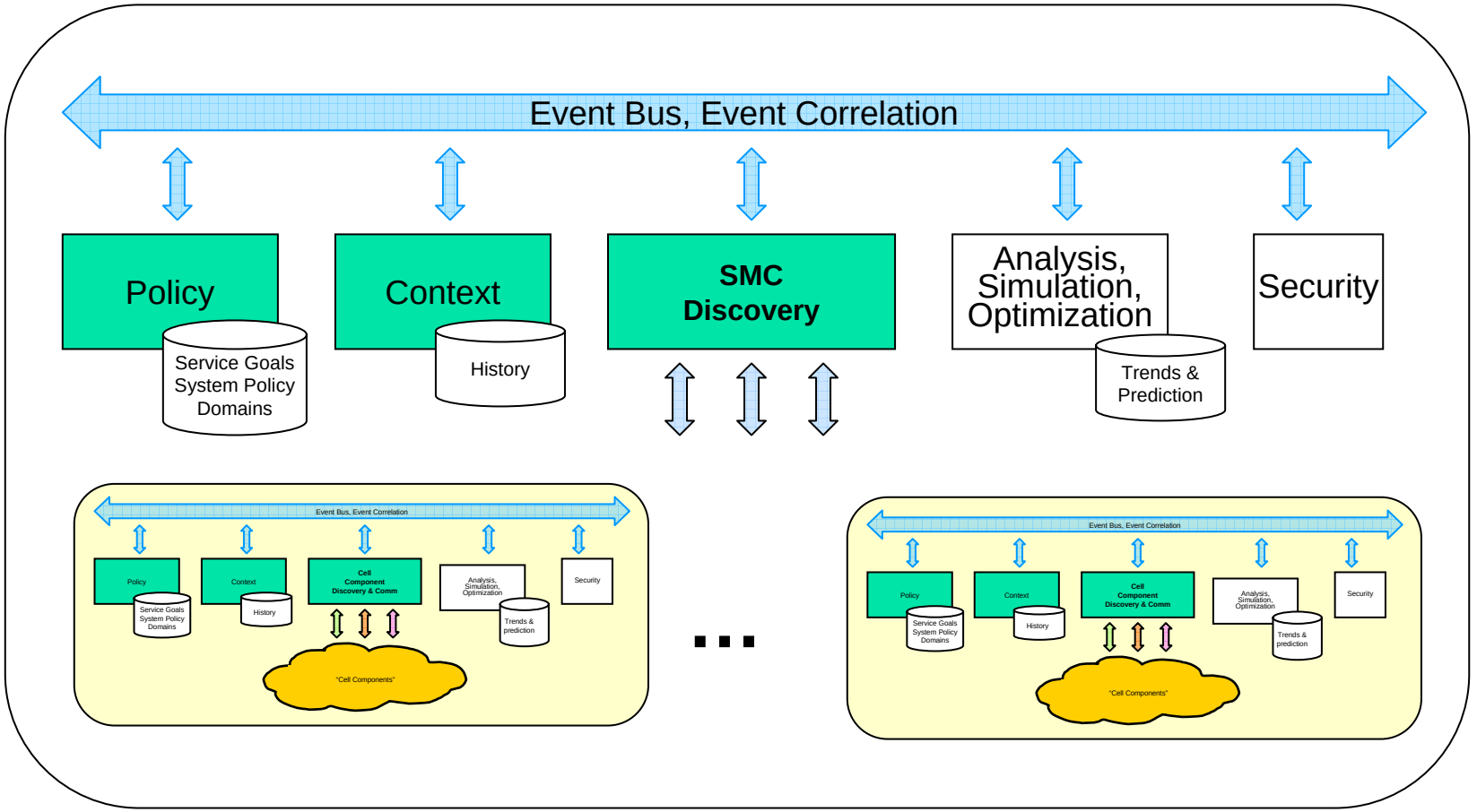


Layered and Federated SMCs

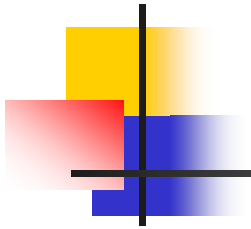


- Layered SMCs: application / services / network
- Peer SMCs (peer devices, peer networks, SLAs...)

SMC Composition



- Enclosing SMC “programs” the nested SMCs



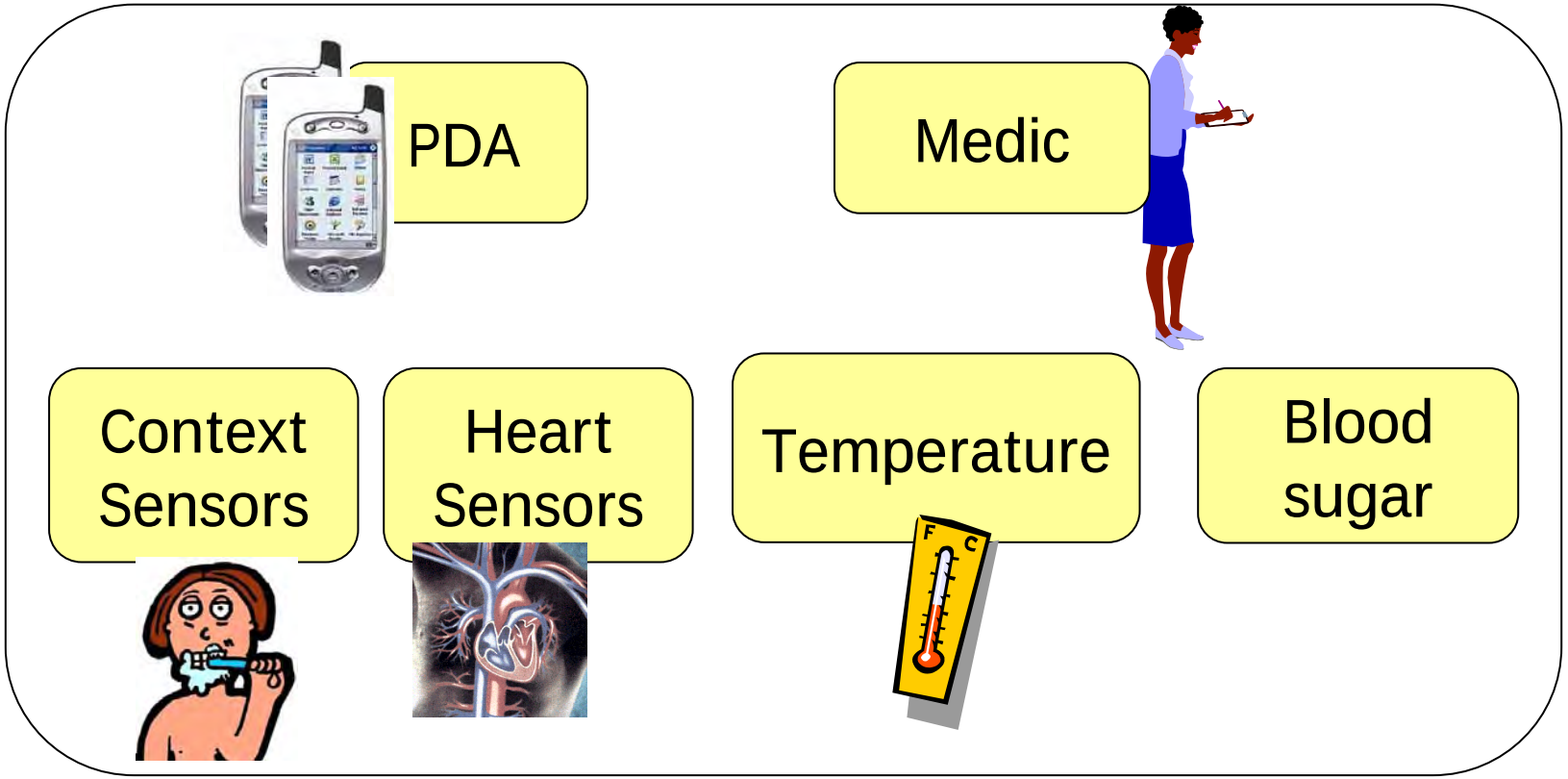
SMC Interactions

Layered - Network SMCs interact with application SMCs, the SMC controlling a heart rate monitor reports to a diagnostic management device, ...

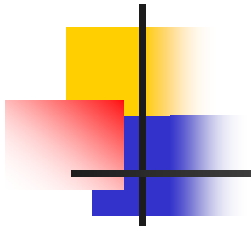
Federated, Peer-to-peer – SMCs for peer devices interact with each other.

SMC Composition – Need to be able to compose SMCs into larger structures e.g., home patient monitoring SMCs "program" individual device SMCs

Body Sensor SMC ‘Roles’



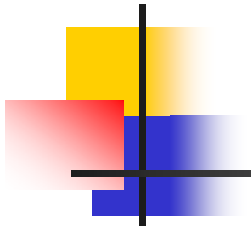
- SMC defines role assignment policies
  + role interaction relationship policies



Discovery Policies

on detect (Xname, Xaddr, Xtype) **->** medic.add (Xname, Xaddr)
    when Xtype = nurse &
            signed (Xaddr.getCertificate, nursingCouncil_PK)
on detect (Xname, Xaddr, Xtype) **->** temperature.add (Xname, Xaddr)
    when Xtype = tempSensor
        .....

every mins (polltime) **->**
    temperature.pollmembers ->
    medic.pollmembers
    .....
    poll all members of a role and remove any which have not responded after max tries.



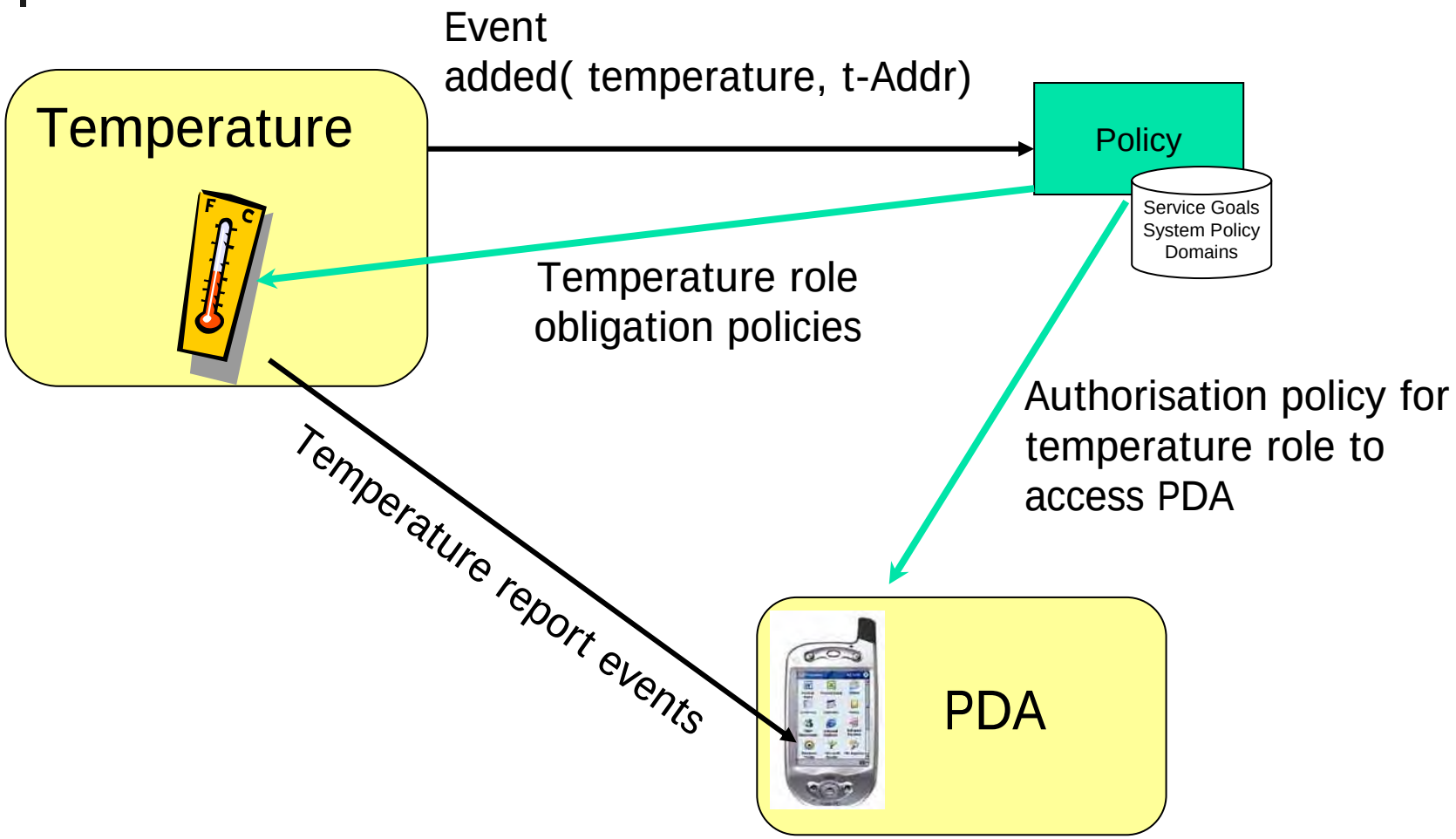
Temperature-PDA Policies

```
tempSensorPolicies {
    every mins (2) ->
        tempSensor.read (tempValue) ->
        tempSensor.tempEvent (tempValue)
            // trigger local event

on tempEvent (tempValue) ->
        pda.reportTemp (tempValue)
        when (tempValue > maxtemp)

auth +  tempSensor -> pda.reportTemp
}
```

Deploying Policies



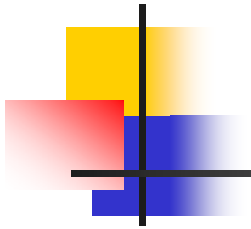
Policies to Protect PDA

on 3* fingerprintfail ->
    pda/policies/bodymonitor.disable ->
    pda/policies/selfprotect.enable ->
    timerEvents.trigger (shutdown, currentTime + 60)

pda/policies/selfprotect
every minutes (5) ->
    sendSMS (07957341, “Stolen PDA”, “ownerID”, currentLocation)

on shutdown ->
    pda.locked ->
    pda.switchoff

Assume this prevents pda from being rebooted or reset without an owner card.

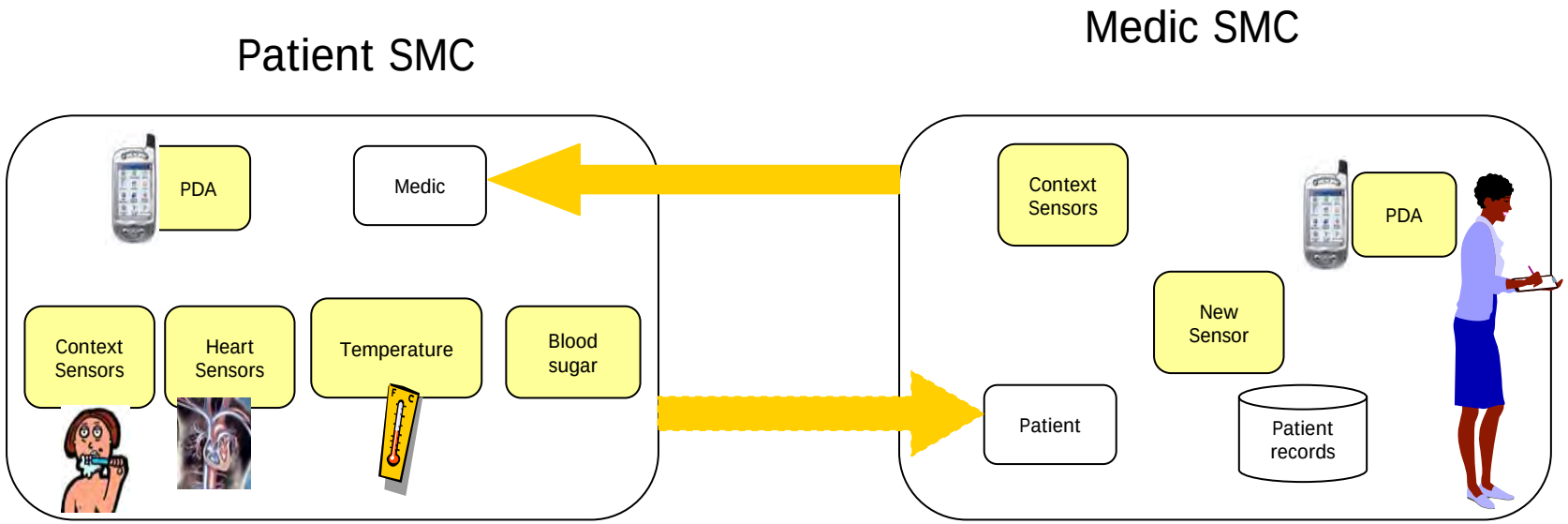


Context aware policies

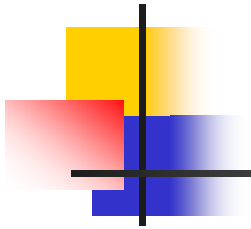
on enterhome ->
    pda/policies/trusted.enable ->
    pda/policies/untrusted.disable

on leavehome ->
    pda/policies/untrusted.enable ->
    pda/policies/trusted.disable

Peer-to-Peer Interactions

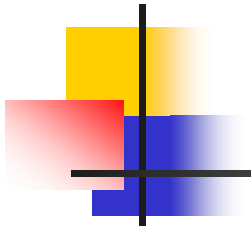


- Assign peer SMC to pre-defined roles within each SMC
- Predefined policies specify obligations and authorisation for entity assigned to role
- Default entity(PDA) interprets obligation policies provided to it.



Other forms of cell interactions

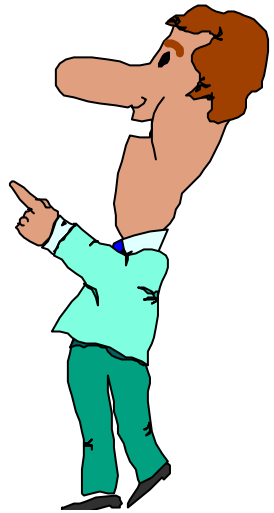
- SMCs define implementable policies
- What about overall management strategy or goals?
- Requires goal refinement
  - Use *refinement patterns* in order to refine goals
    - Domain independent refinement patterns
    - Domain specific refinement patterns
  - Strategy defines how the goals are achieved. Note, there can be multiple strategies to achieve the same goals.
  - Derive strategy from goals and system description through abduction
- Very hard, not implementable on PDAs
- A Goal-based Approach to Policy Refinement by A Bandara et.al http://www.doc.ic.ac.uk/~bandara/publications.shtml



Contents

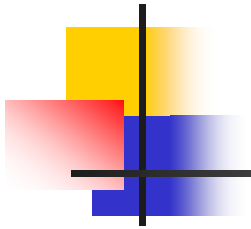
- Grand challenges
- What is pervasive computing
- Current Technology
- Engineering Challenges
- Theoretical Challenges
- Management issues
- **Future activities & conclusions**

Current UK Activities



- Equator IRC http://www.equator.ac.uk/
- DTI Next Wave Technologies http://www.nextwave.org.uk/index.htm
- EPSRC WINES Program
- Mostly engineering
- Need to develop scientific theory and engineering principles in a tight experimental loop
- UK-UbiNet + Grand Challenges

http://www-dse.doc.ic.ac.uk/Projects/UbiNet/links.html



Conclusion

- Currently pervasive systems are more hype than reality
- Some component technologies are available
- Technology problems - seamless communications, power
- Management problems - adaptive self management, privacy
- Most research focuses on Engineering aspects
- No theory to underpin understanding, analysis & design
- SMC provides a scope for theoretical analysis and implementation.