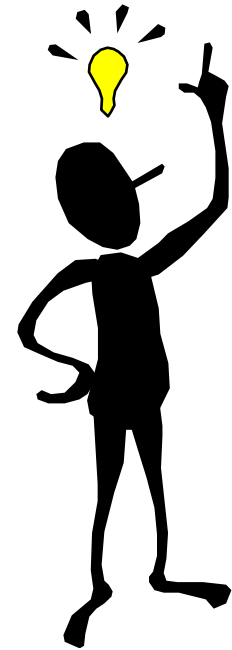


Evaluation of Ubiquitous Computing Systems: Exercise in Frustration or Research Opportunities?



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Intel
Research
A division of Intel Labs

Announcements

- **3 conferences in ubicomp/pervasive computing**
 - Pervasive 2002: www.pervasive2002.org, Zurich, August 26 – 28
 - Ubicomp 2002: www.ubicomp.org, Goteburg, Sept. 29 – Oct. 1
 - IEEE Pervasive Computing: www.percom.org, Dallas, March 23 – 26 (October 1)
- **Doctoral Consortium**
- **Lots of workshops and specialized conferences**
- **Previous Ubicomp Seminar**
 - Abstract book
 - Report

Outline

- **Evaluation**
 - What it is
 - Why it's good for you
- **Overview of evaluation**
- **Types of evaluation and examples**

What is Evaluation?

- **Appraisal of the value of a system**
- **Examining a system to determine extent to which certain properties are present**

4 Reasons Why Evaluation is Your Friend



Why is it good for you?

- **Necessary for validating your ideas**
 - Needed for any research project: thesis
- **Know when to stop**
 - Have a hypothesis and need to know that it's true (or false)
- **Compare others work to your own**
- **Compare others work against each other**

Types of Evaluation

- Quantitative
- Qualitative

- Formative
- Summative

application
service
data management
network
system
architecture
hardware

Few Differences with Ubicomp

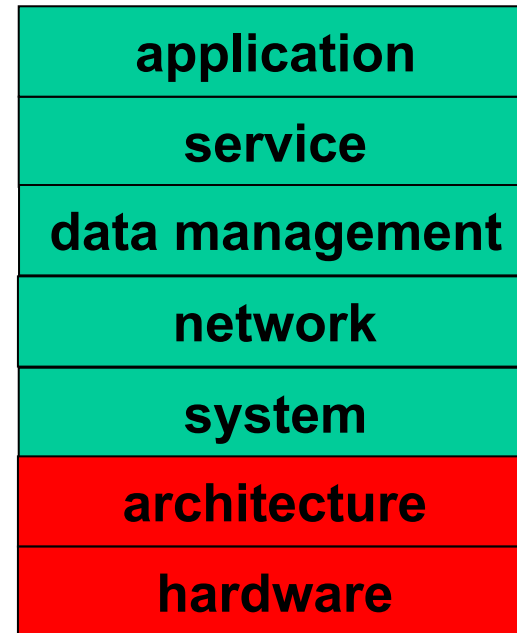
- **What is transparent?**
- **Implications of transparency**
- **Living with system - critical mass needed?**
- **Failure recovery/graceful degradation**
- **Evolvability**
- **Scalability**
- **Garbage collection at many levels**
- **Cost - not just dollars, but computational resources, battery power, bandwidth, devices, infrastructure needed**

Example System

- **Pick on someone**

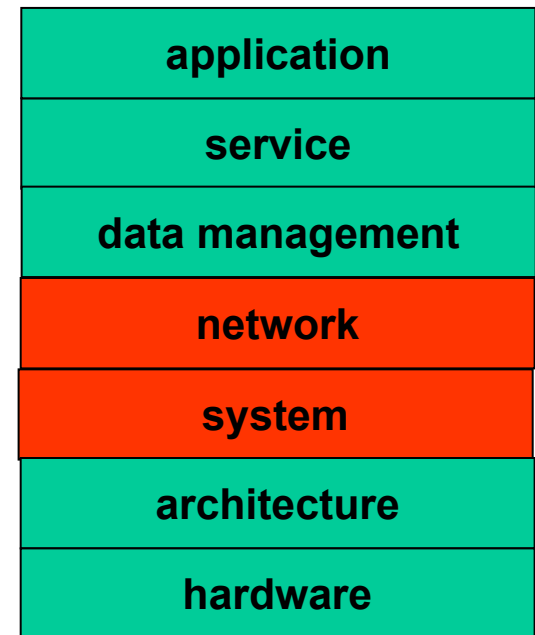
Hardware and architecture

- **Interference between devices**
- **Resource scheduling**
- **Device usability**



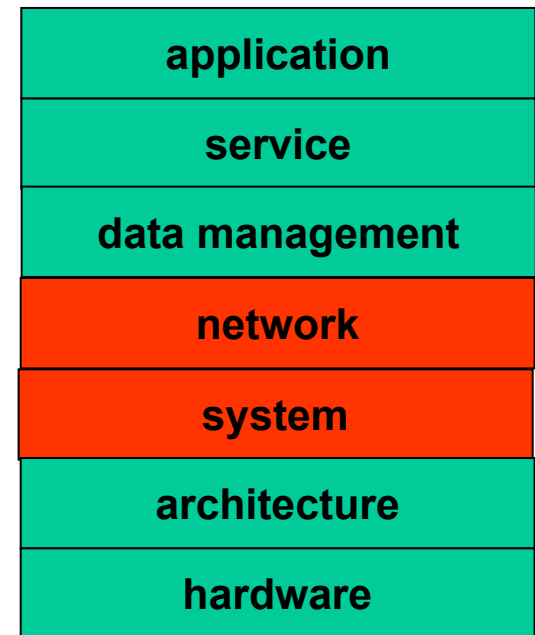
Distributed Computing: Systems/Networking Evaluation

- **Bandwidth constraints**
- **Connectivity**
- **Performance**



Distributed Computing: Systems/Networking Evaluation

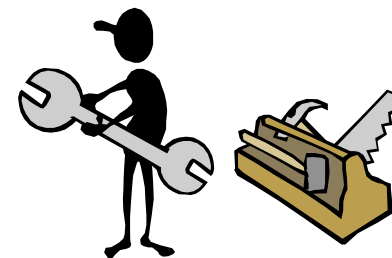
- **New functionality: qualitative**
 - does it perform the job you wanted it to do?
- **Improving functionality: quantitative**
 - Throughput, latency (Hannes), speed, power usage
 - Bigger, smaller, faster, more efficient, more accurate (Jan)
 - Comparable results, but with fewer assumptions/restrictions (Kulpreet)
 - Simulation accepted methodology



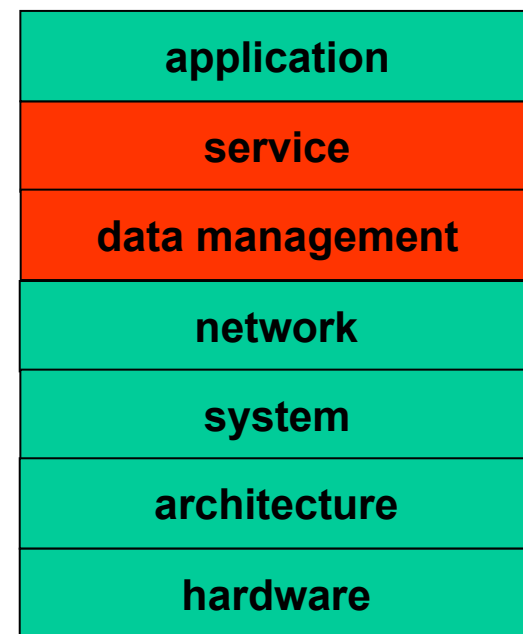
Distributed Computing: Systems/Networking Evaluation

- Differences with ubicomp
 - What are they?
 - More nodes
 - Greater latency
 - ???
 - Harder to simulate
 - What else?
 - Can we use the same techniques as before?

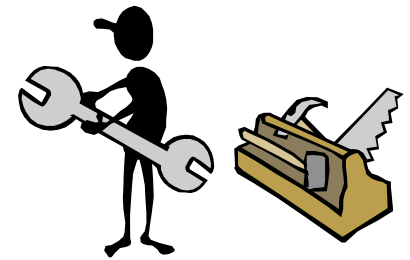
Middleware and toolkits



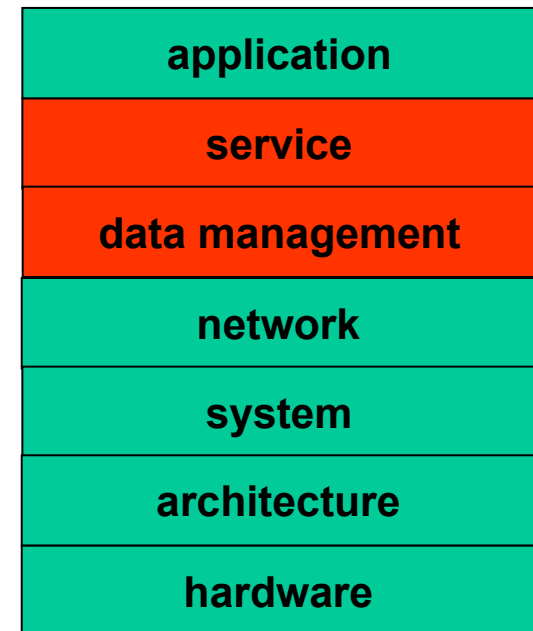
- **New functionality**
 - qualitative
- **Enhanced functionality**
 - qualitative and quantitative



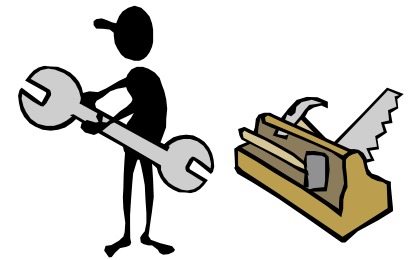
Middleware and toolkits



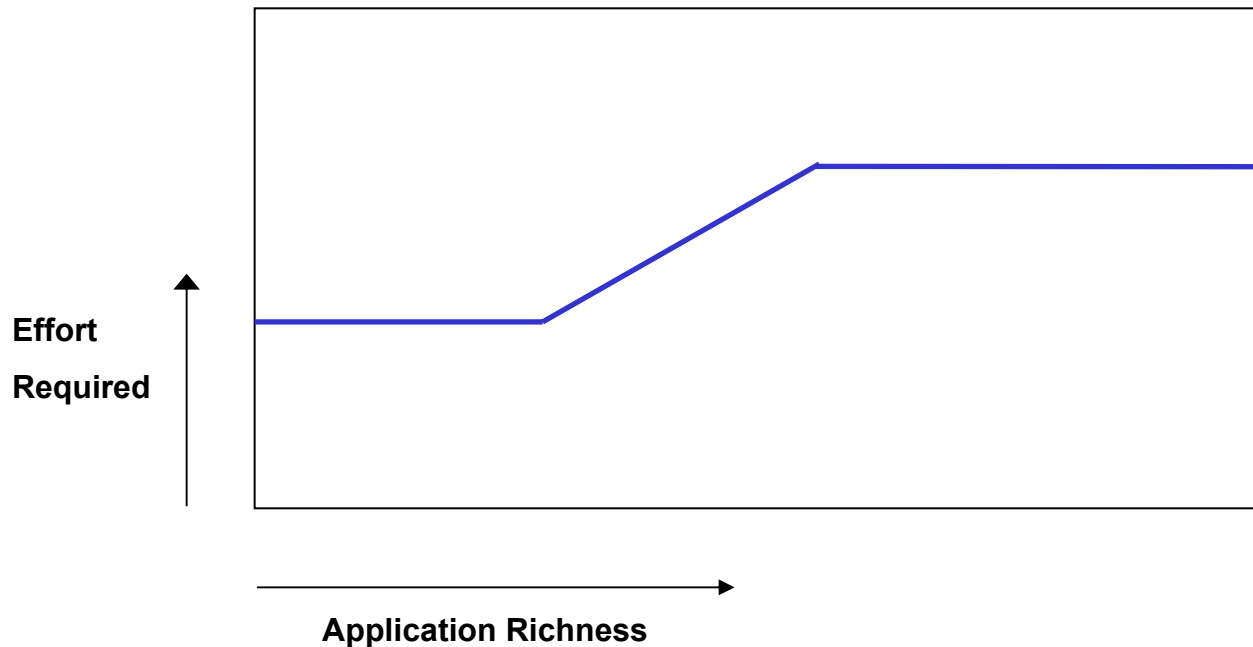
- **Correct decomposition into services**
- **Communications**
- **Reliability**
- **Latency in service discovery**



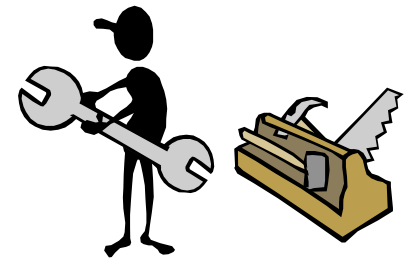
Middleware and toolkits



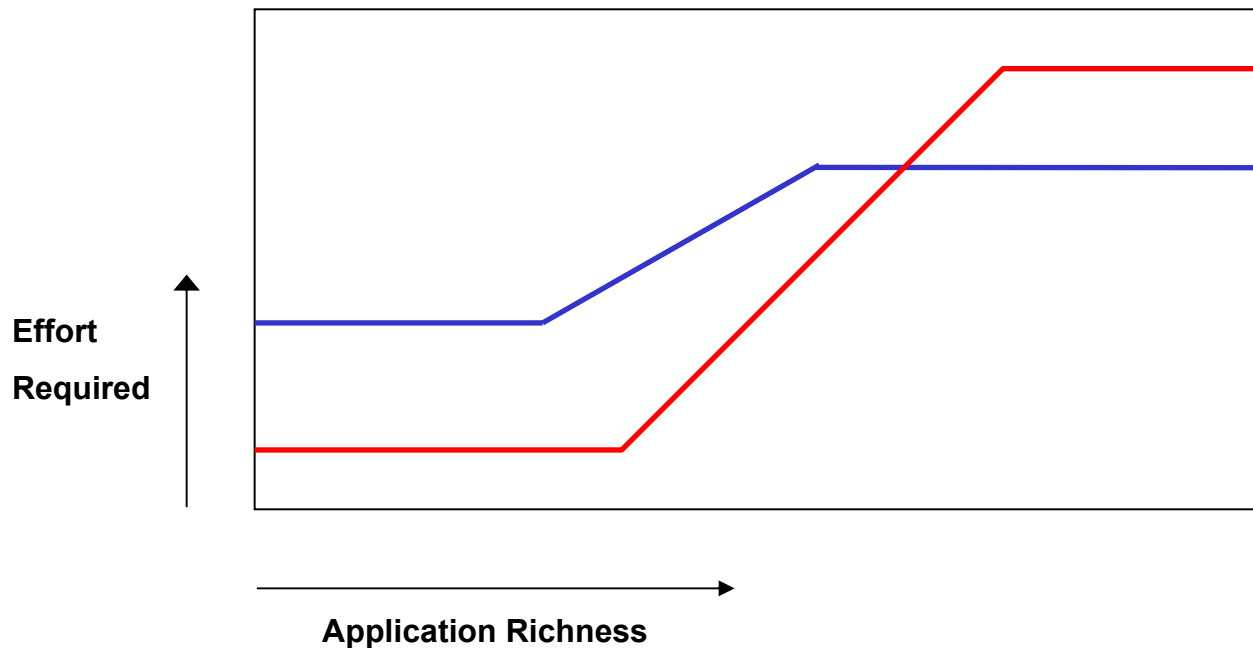
- Floors and ceilings



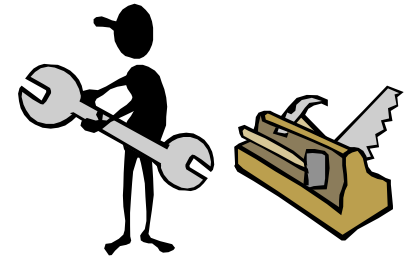
Middleware and toolkits



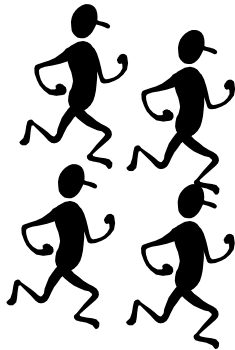
- Floors and ceilings



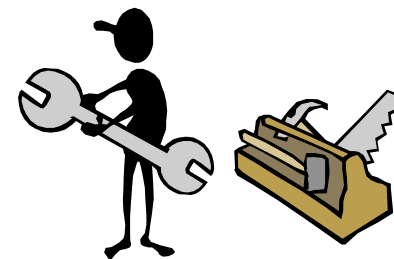
Middleware and toolkits



- **My approach**
 - Lower the floor: rebuild existing apps, but show it's *easier* (user modeling app)
 - Raise the ceiling: build new, *difficult* to build apps (Thomas)
 - If you build it, they will come (John)
 - Explore the design space



Middleware and toolkits



- **Differences with ubicomp**
 - Not too much
 - Increased complexity
 - Increased constraints
 - ???

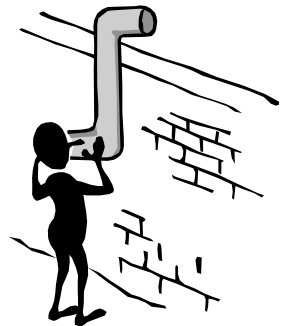
Applications

- Task focused:
qualitative and
quantitative
- Non-task focused:
qualitative and
quantitative

application
service
data management
network
system
architecture
hardware

Applications

- **Done today:**
 - **Quantitative: objective**
 - Completion times, accuracy
 - Instrumentation
 - **Qualitative: subjective**
 - What users think: happier, more efficient
 - Questionnaires, interviews, monitor
 - [Table of techniques](#)

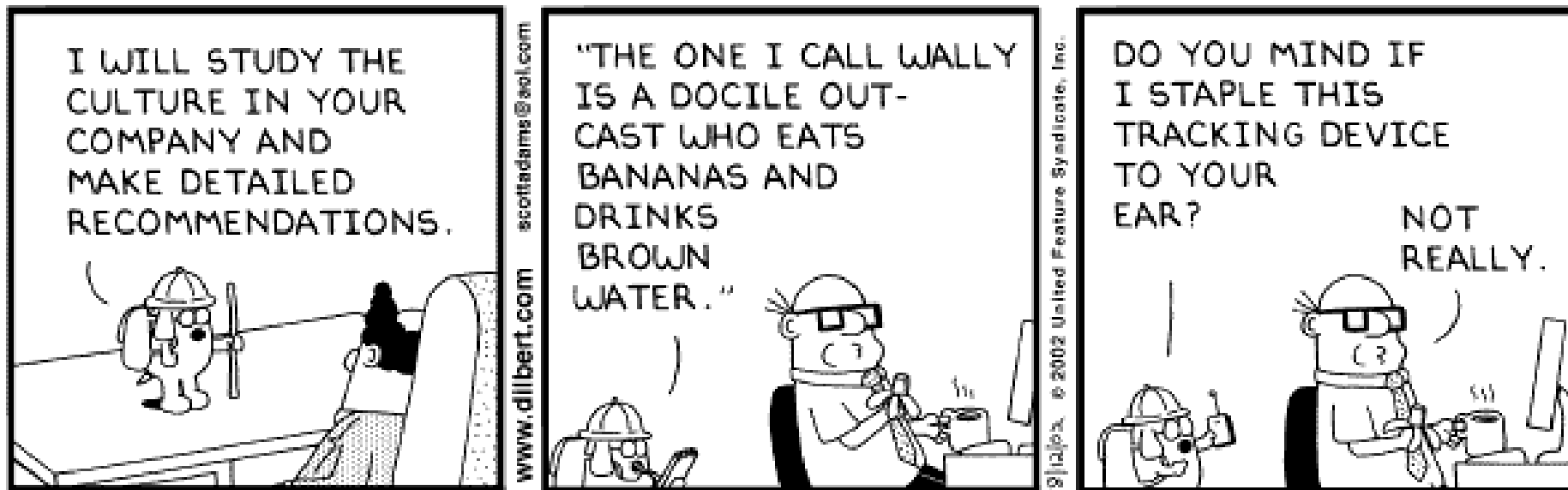


Applications

- **Useful, usable**
- **Interesting/fun**
- **Predictability and mental model**
- **Forgiving system: recovery**

- **Bleeding edge technology**
- **Novelty**
- **Unanticipated uses**
- **Quantitative metrics**

Applications: Ubicomp Differences



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here: human vs. network performance

Applications: Ubicomp Differences

- **Monitoring duration**
- **Time to get used to technology:
remove the “wow” factor**
- **Often interested in the infrequent odd cases**
- **Not always solving today’s problems:
comparison points**

Applications: Monitoring

- Real world: hard to monitor**
- Is an environment with cameras, microphones, computers capturing information about users and interactions a ubicomp system?**
- YES!**

Applications: Monitoring

- Existing monitoring setups are ubicomp environments
- Setup even more complex for monitoring distributed, mobile ubicomp apps
- Have to build a ubicomp system to evaluate your ubicomp system!
 - Chicken and egg problem

Applications: Techniques

- **Formative:**
 - **Beeper studies:** want to know what users are thinking (directly)
 - **Look for patterns:** want to know what users are thinking (indirectly)
- **Summative:**
 - **Task oriented:** lab studies
 - **Living laboratory**
 - **Modifying existing evaluation techniques**

Examples

- **Star Trek doors**
 - Why such a hard design problem
 - Leads to hard evaluation problem
- **Classroom 2000 & Aware Home**
 - Living Laboratory
 - Longitudinal studies
 - Demo
- **Ambient displays**



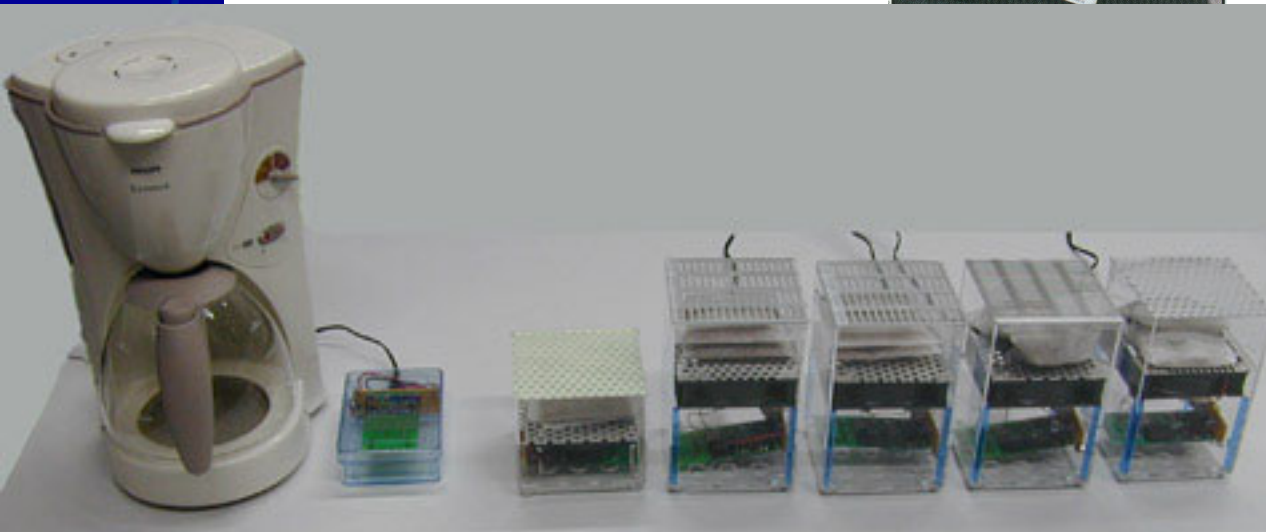
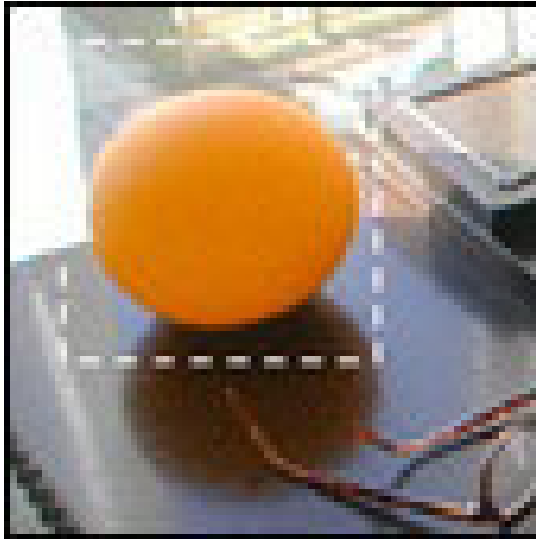
Ambient Displays

(Dey, Mankoff and many students)

- Peripheral cues of some (potentially) interesting event in your environment
- Any modality: listen, feel, smell, see, taste
- Typically abstracted information
- Use perceptual channels that aren't already overloaded
- Provide awareness through everyday objects

Innovative Ambient Displays

(many others)



Interesting Issues

- Explore the design space: toolkit, individual examples
- Provide information that is *relevant* to a space or a group of people
- Do it in an *interesting/provocative/aesthetic* way
 - Transitions: overview to specific; static to interactive
 - Enhance everyday artifacts
- Have some way of *measuring* the results

Design Space Exploration

- **Aesthetics**
- **Obtrusiveness**
- **Notification**
- **Persistence**
- **Temporal context**
- **Overview to detail transition**
- **Audience**
- **Modality**
- **Level of abstraction**
- **Interactivity**
- **Location**
- **Content**

Relevant Information

- **Contextually dependent**
- **Looked at needs of small and large workgroups in university settings**
- **Starting to look at health:**
 - **Individual health of an elderly person**
 - **Aggregate health of a city**

Interesting Displays

- Tied to relevance of information
- Aesthetically pleasing
- Displays that both blend into the user's environment when not needed and pop out when desired

Evaluation

- **Change people's awareness of information**
- **Change people's behavior**
- **Existing techniques don't seem appropriate**
 - **Meant for focused tasks**
- **Modify existing techniques**

Our Ambient Displays

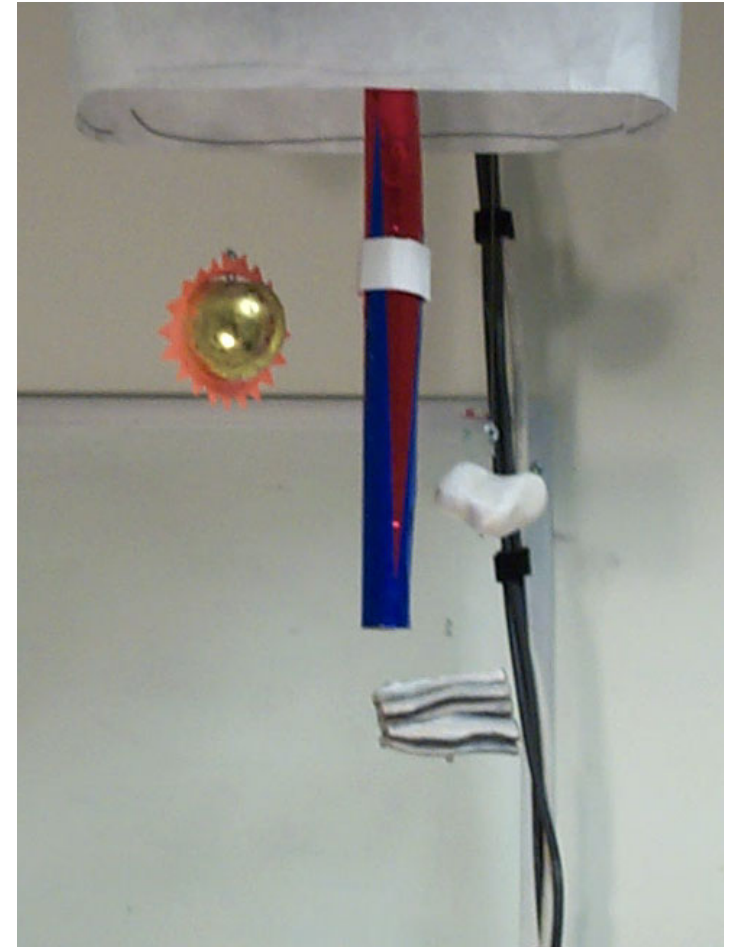
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3	0273.6	MGRG:0467.1	MOLXA:2,796	MTSC:0215.6	NEOF:0393.7	NOLO:0102.0	NUCO:0105.5	ODFL:0110.1	ORCT:0076.3	PF
4	0179.9	MGRP:0004.9	MOND:0602.2	MTSL:0007.1	NEOG:0038.1	NOOF:0062.4	NUFO:0334.0	ODSY:0316.8	OREC:0112.7	PF
5	0000.0	MHCO:0003.6	MONB:0673.7	MTSN:0021.8	NEOL:0038.4	NOPT:0034.8	NUHC:0173.5	OFDC:0516.4	ORFR:0004.3	PC
6	0077.8	MHLX:0000.0	MONI:1,709	MTSX:0000.0	NEOM:0002.3	NOVA:0034.4	NURM:0053.0	OGLE:0073.5	ORLY:1,585	PC
7	0311.6	MHMY:0005.1	MONM:0004.6	MTWM:0190.4	NEOT:0067.0	NOVB:0066.5	NUTR:0063.2	OGNC:0027.9	ORPH:0123.2	PC
8	0162.9	MHUT:0163.5	MOSY:0626.6	MTXC:0069.0	NERAY:0265.5	NOVI:0011.2	NVAL:0089.0	OGSI:0418.9	ORTC:0064.6	PC
9	0418.2	MICC:0615.2	MOVE:0455.1	MUEL:0034.5	NERX:0142.8	NOVL:1,587	NVAX:0259.8	OICO:0018.0	ORYX:0099.4	PC
0	0005.4	MICT:0148.7	MOYC:0011.2	MUSE:1,072	NESY:0085.6	NOVN:0391.9	NVDA:9,118	OIMM:0795.4	OSBC:0225.5	PC
1	0028.4	MIDD:0058.6	MPET:0019.5	MVBI:0364.9	NETA:4,139	NOVT:0185.0	NVDC:0004.8	OKSB:0110.1	OSCA:0255.5	PC
2	0074.0	MIEC:0535.9	MPML:0010.6	MVCO:0005.9	NETE:0537.8	NPBC:0473.0	NVDH:0221.0	OLAB:0011.9	OSIP:1,694	PC
3	0010.4	MIHL:0323.6	MPWG:0022.3	MVIS:0165.7	NETM:0077.5	NPLS:0034.2	NVGN:0000.1	OLDB:1,504	OSIS:0148.8	PC
4	0014.8	MIKN:0094.8	MPWR:0029.1	MVSN:1,705	NETP:0067.2	NPRO:0308.5	NVIC:0002.8	OLGC:0179.5	OSKY:0044.5	PC
5	0017.5	MIKR:0011.8	MRAE:0553.5	MWAY:0032.4	NETZ:0007.0	NPSI:0249.4	NVLD:0097.6	OLGR:0016.4	OSTE:0111.6	PC
6	0121.6	MILB:0008.0	MRBA:0072.2	MWGP:0150.8	NBAC:0004.2	NPSP:1,012	NVLS:6,164	OLOG:0368.5	OSTX:0037.1	PC
7	0034.7	MILT:0009.0	MRBK:3,106	MWRK:0036.9	NBWH:0115.5	NRCI:0062.9	NVMI:0061.0	OMCL:0172.4	OSUR:0436.9	PC
8	0424.5	MIMS:0466.0	MRCY:0764.0	MXBIF:0154.0	NBWP:0893.1	NRGN:0283.4	NVTL:0009.3	OMED:0018.1	OTCM:0132.9	PC
9	0360.5	MIND:0041.8	MUGE:0035.3	MXICY:0268.4	NBWR:0005.5	NRGY:0153.7	NWAC:1,553	OMEF:0269.2	OTEC:0194.8	PC
0	0300.6	MINI:0517.2	MUGO:0008.5	MXIM:18,401	NEXL:0033.9	NRIM:0083.6	NWAY:0006.8	OMNE:0033.4	OTEX:0593.3	PC
1	0130.4	MIPS:0483.6	MRNT:1,166	MXRE:0655.0	NEXM:0081.5	NRRD:0074.4	NWBT:0083.1	OMTL:0009.8	OTFC:0060.4	PC
2	0014.9	MIPSB:0441.6	MROE:0065.9	MXWL:0102.1	NEXT:0070.3	NSANY:14,290	NWFL:0045.7	ONCO:0154.2	OTGS:0359.5	PC
3	0056.0	MITK:0019.8	MROI:0518.7	MYGN:1,096	NFLD:0128.0	NSAT:0053.6	NWFL:0046.0	ONCY:0000.0	OTRK:0885.9	PC
4	0247.4	MITSY:7,530	MRSA:0006.5	MYST:0023.2	NGAS:0003.5	NSCN:1,783	NWIR:0014.7	ONDI:0085.3	OTTR:0664.7	PC
5	010,045	MITY:0047.5	MRTI:0010.6	NABI:0366.0	NGEN:0112.6	NSDA:0403.8	NWLLA:0383.2	ONES:0130.7	OTWO:0043.6	PD
6	0070.5	MKIE:0048.4	MRTN:0075.1	NADX:0085.6	NGPS:0016.9	NSDB:0054.0	NWLL:0000.4	ONEV:0009.6	OUA:0001.1	PD
7	1,113	MKSI:1,060	MRVC:0359.9	NAFC:0350.4	NGRU:0038.6	NSBC:0039.6	NWPR:0114.0	ONFC:0080.6	OUTL:0016.5	PD
8	0018.8	MKTAY:0004.8	MRVL:4,766	NAII:0013.5	NHCH:0169.3	NSFC:0096.4	NWRE:0075.2	ONIS:0974.4	OVBC:0076.0	PD
9	0027.6	MKTG:0015.4	MRVT:0182.0	NANO:0258.3	NHCE:0010.1	NSIL:0061.8	NWSE:0534.1	ONNN:0555.5	OVER:1,968	PD

Current Status

- **Deployment complete**
- **Collected data**
 - Questionnaires and evaluation
- **Analyzing data**
 - Heuristic evaluation → new heuristics

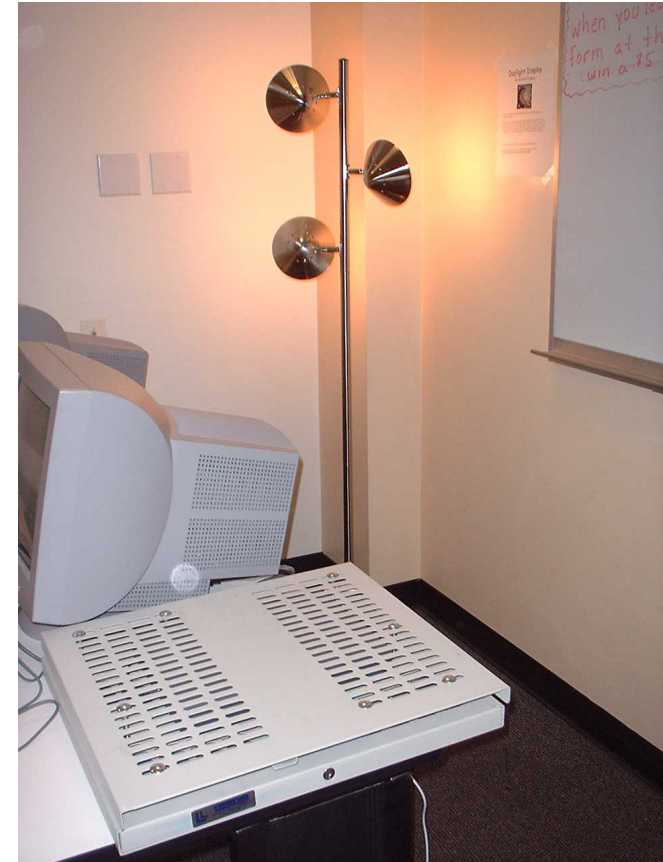
Our Ambient Displays



Our Ambient Displays



Our Ambient Displays



Current Status

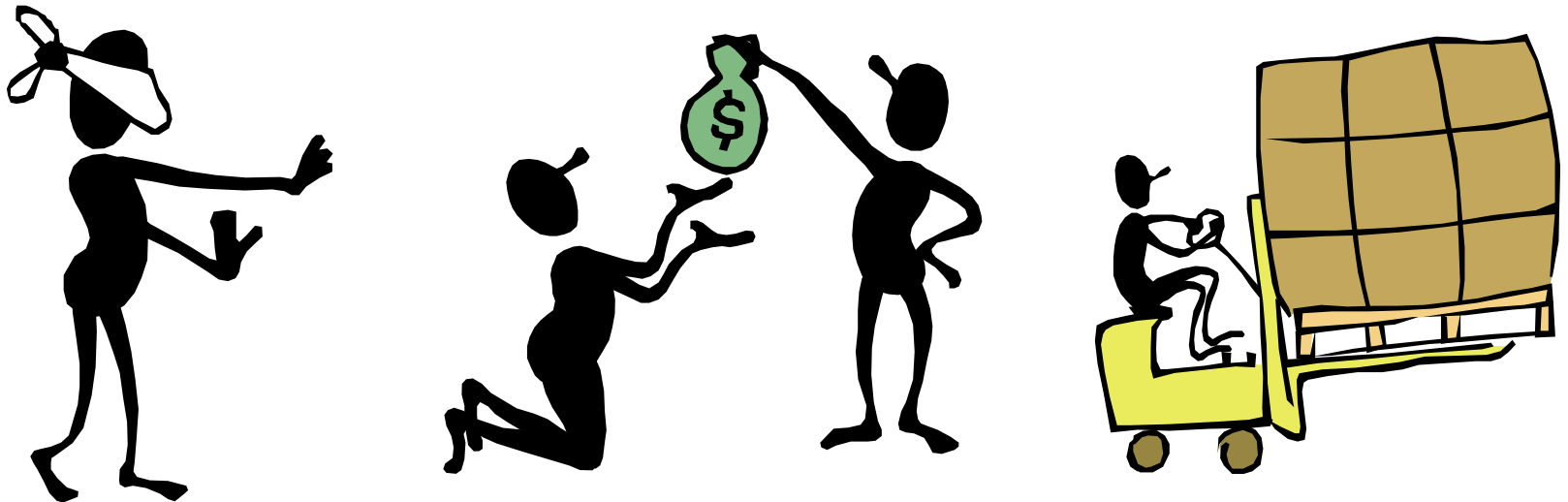
- **Displays deployed and evaluation data collected**
- **Evaluation: Questionnaires, monitoring and instrumentation**
- **Results presented on Thursday**

Examples

- **GUIDE:**
 - monitoring, interviews, questionnaires, instrumentation
- **Exploratorium:**
 - John?

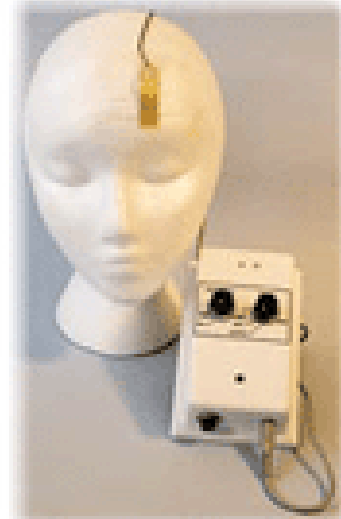
Examples

- Precision Agriculture
 - Working with wine
 - Evaluation



Support for the Disabled: Ambiguity in Context

- Mobile and speaking-impaired users: wheelchair-bound, speech synthesis users
- Difficulty performing everyday activities: communication



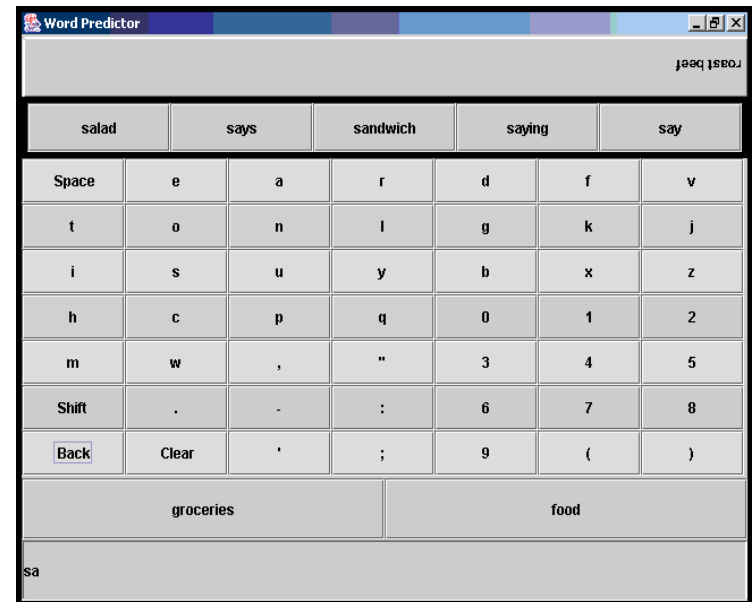
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Support for the Disabled: Ambiguity in Context

- Hypothesis: context can improve word prediction
- Context: location, time, vocabulary, history
- Choose vocabularies and filter words based on context and recent words chosen

Support for the Disabled: Ambiguity in Context

- Proof of concept built using GPS unit and laptop
- Examining mediation strategies to correct context
- Starting evaluation of usefulness



Support for the Disabled: Video & Next Steps

- VIDEO
 - Instrument parts of downtown Berkeley
 - Instrument wheelchairs
 - Support navigation
 - Start evaluation tests



Dangers of Application Evaluation

- **Computer scientists like to see hard science: no touchy-feely**
- **Novelty is hard to demonstrate and not always best way to advance field**
- **Hard to build a complete system, but often need to, to reasonably evaluate**
- **Good studies are hard to design and deploy: e.g. focus groups and consumer products**

Conclusions

- **When starting research project, have clear hypothesis!**
- **Evaluation of ubiquitous computing systems is non-trivial, but not impossible**
- **Open research questions**
- **Happy to act as a resource**