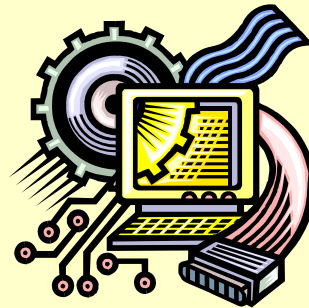


# Physical User Interfaces

What they are and how to build them

**Saul Greenberg**

University of Calgary  
CPSC 581



## New disciplines and genres of computing

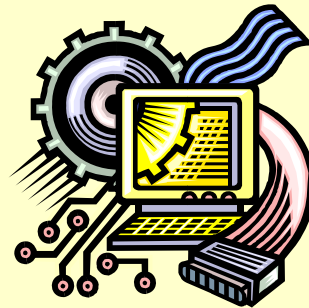
- ubiquitous computing
- pervasive computing
- context-aware computing
- mixed / augmented reality
- attentive user interfaces
- wearable computing
- sensor networks
- information appliances
- tangible user interfaces
- alternative input and output devices
- cooperative buildings
- smart homes
- smart furniture / clothes
- consumer robotics ...

## Goals

---

### You will know

- various genres and opportunities of physical user interfaces
- basic hardware building blocks available to you
- how to get started building your own physical user interfaces



## Technology Trends

---

### Displays

- very small (inches) to very large (walls)

### Processors:

- cheap, small, dedicated, microprocessors

### Analog / Digital Device Control

- actuators, sensors, motors, switches, lights...

### Low Power

- small batteries, solar (?)

### Wireless

- Wireless ethernet, infrared, mobile standards, Bluetooth (in-room), in-building, metropolitan

### Operating systems

- Linux on a chip, Windows CE, ...

### Packaging

- non-conventional devices

## Physical Things

---

### People

- know **affordances** and **physics** of things
- develop **social practices**
- add **meanings**
- situate them in **everyday physical settings**



## Physical User Interfaces – Why?

---

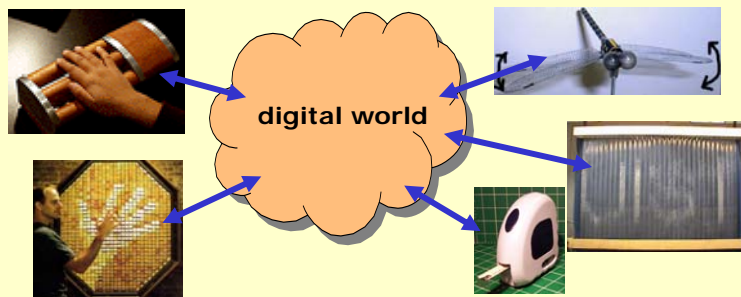
Exploit people's highly nuanced **interaction experiences** and **social practices** when using objects situated in **everyday physical settings**



## Physical User Interfaces - Scope

Computer-controlled interactive physical devices situated in a real-world setting

- **appliance-like**: designed for particular context and uses
- **composition**: microcontroller, actuators, sensors, motors...
- **connectivity**: with digital computers and information



## Mark Weiser *Xerox Parc*

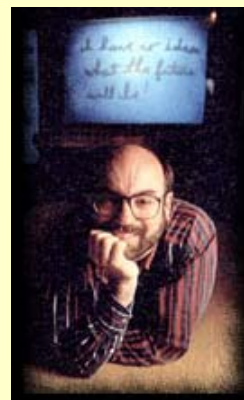
### Ubiquitous Computing - *many computers per person*

"It is invisible, everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere. Its highest ideal is to make a computer so embedded, so fitting, so natural, that we use it without even thinking about it."

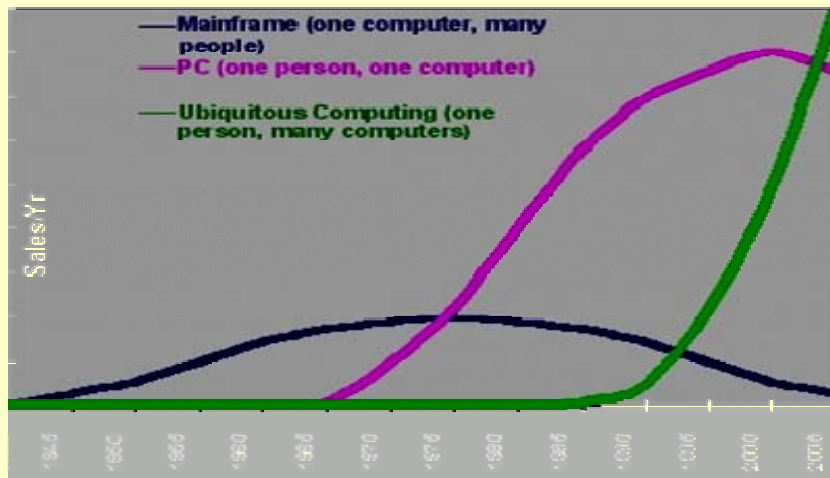
#### invisible

- designed to fit
- exploits our everyday participation in the world

Source: Mark Weiser's Ubiquitous Computing web site



## Ubicomp Technology Trends



Source: Mark Weiser's Ubicomp web site

## Hiroshi Ishii *MIT Media Lab*

### Tangible User Interfaces

"gives physical form to digital information, seamlessly couple the dual worlds of bits and atoms"

- from painted bits to tangible bits
- **input:** grasp and manipulate
- **output:** change physical properties of object



Source: Hiroshi Ishii publications

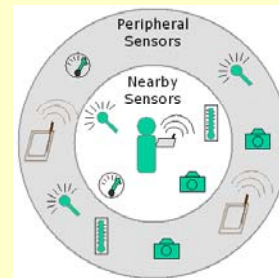
## Context-Aware Computing

### Context as information

- ... characterizes a situation of a person, place or object relevant to the interaction between a user and an application
  - location
  - identity
  - state and activities of people, groups
  - state of computational and physical objects

### Context-aware computing

- uses contextual information to
  - selectively present information and services
  - automatically execute a service
  - attach context information for later retrieval



Source: Dey, Abowd and Salber, HCI Journal 2001; Image from Hong and Landay (Berkeley)

## Situated Computing

### Exploits our everyday participation in our world

- physicality
- placement in space
- affordances
- proximity
- is out here with us
- is in many small and large places, including trivial ones



Source: Mark Weiser's UbicCom web site

## Outline

---

### Styles of use

- ambient displays
- foreground interaction
- physical controls
- tagging and identity
- attentive user interfaces
- ...

### How to build them

- building blocks
- hardware / software platforms
- case study: phidgets

Style 1

## Ambient displays

---

Information displayed at the periphery of attention

physical expression:

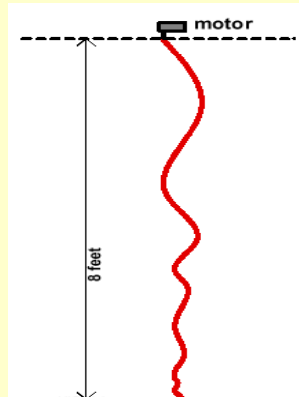
- light, sound, airflow, movement, pattern changes...



Style 1 - ambient displays

## Dangling String

---



- freely hangs from ceiling in hallway
- connected to ethernet
- 0.1 turn per packet

Natalie Jeremijenko (1995)

Source: Mark Weiser's Ubiquitous web site

Style 1 - ambient displays

## Dangling String

---



- freely hangs from ceiling in hallway
- connected to ethernet
- 0.1 turn per packet

- spins madly when busy
- wiggles gently most of the time
- can be seen by those in the hallway
- can be heard, peripherally

- gives body to something virtual
- part of environment, like a breeze

Natalie Jeremijenko (1995)

Source: Mark Weiser's Ubiquitous web site



Style 1 - ambient displays

## **Ambient Room**

---



Source: Tangible Media Group web site, ACM CHI'98

Style 1 - ambient displays

## **Information Perculator**

---

bubbles of digital patterns



Source: Heiner, Hudson & Tanaka

Style 1 - ambient displays

## Information Perculator

---

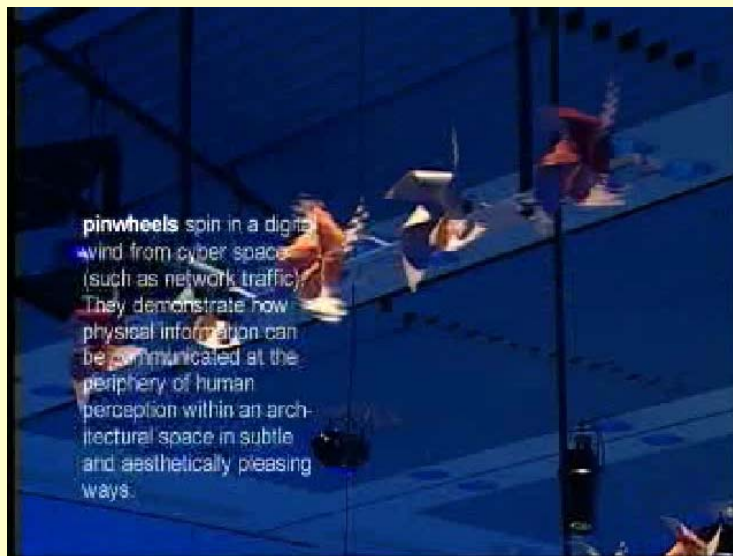
bubbles of digital patterns



Source: Heiner, Hudson & Tanaka

## Pinwheels

---



Extracted from Tangible Media Group web site

Style 2

## **Foreground interactions**

---

Information displayed at the foreground of attention

physical expression:

- conscious intentional interactions
- grasping, direct feedback...



Style 2 - foreground interaction

## **Triangles**

---

Connecting triangles create a digital story

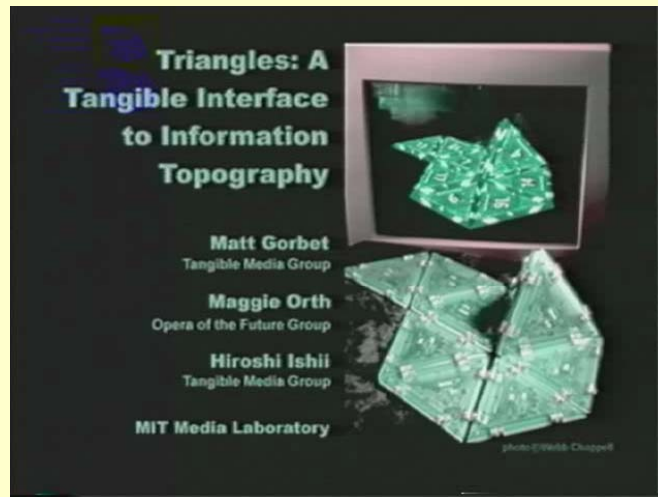


Source: Tangible Media Group web site

Style 2 - foreground interaction

## Triangles

Connecting triangles create a digital story



Source: Tangible Media Group web site

Style 2 - foreground interaction

## Music Bottles



movement and uncorking of the bottles controls digital contents

Source: Tangible Media Group web site

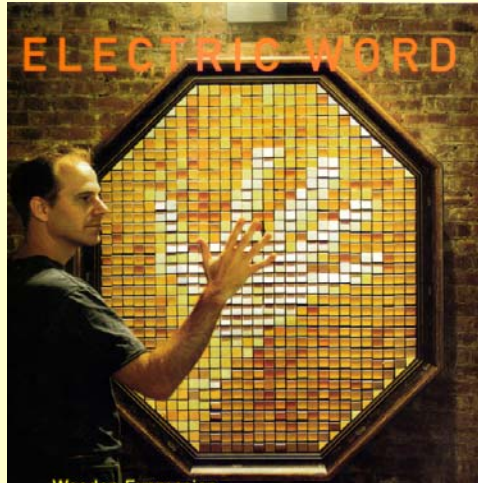
Ishii, MIT

Style 2 - foreground interaction

## Wooden Mirror

---

Wood pixels reflect image



Source: Daniel Rozin, NYU

Style 2 - foreground interaction

## Wooden Mirror

---

Wood pixels reflect image



Source: Daniel Rozin, NYU

Style 2 - foreground interaction

## IAMASCOPE

---



**IAMAscope**  
**- Sidney Fels (ATR)**

Source: Sydney Fels, UBC

Style 3

## Physical controls to GUIs

---

richer physical interface



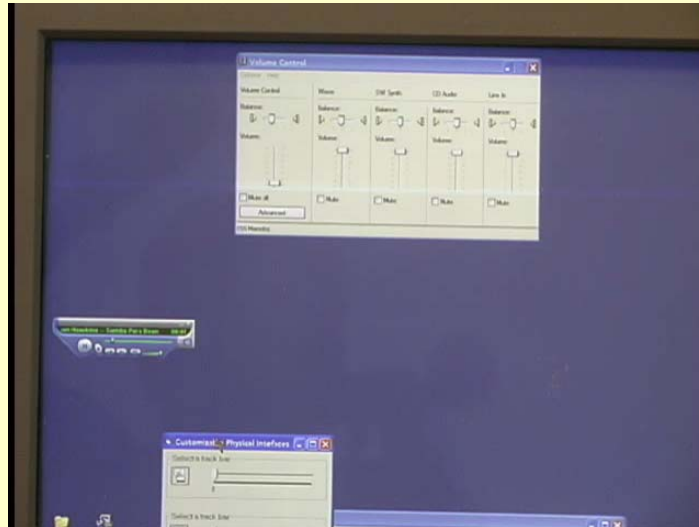
**Sketchpad excerpts, CHI'83**

Source: CHI-83



Style 3 - physical controls

## Customizable User Interfaces



Source: Saul Greenberg, UIST 2002

Style 3 - physical controls

## Manipulative User Interfaces

Manipulative User Interfaces:  
Exploring Physically Embodied  
User Interfaces  
(3:31)

Anuj Gujar, Kenneth P. Fishkin,  
Beverly L. Harrison, and Roy Want

Xerox Palo Alto Research Center

ACM CHI'99 Video Proceedings



Style 4

## **Tagging and Identity**

---

Tags identify and link physical objects to computer information



Source: Xerox PARC, CHI'00 Video Proceedings

Style 4 - tagging and identity

## **mediaBlocks**

---



Source: Tangible Media Group, ACM CHI'99 Video Proceedings



Style 4 - tagging and identity

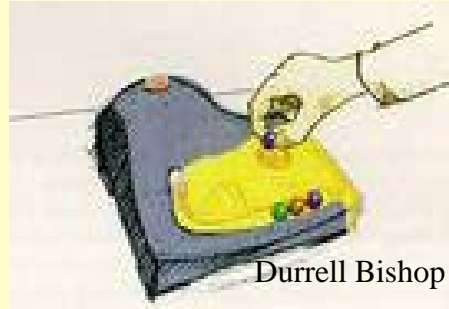
## Marble Answering Machine

---

Incoming voice messages are physically instantiated as marbles.

The user can grasp the message (marble) and drop it into an indentation in the machine to play the message.

The user can also place the marble onto an augmented telephone, thus dialing the caller automatically.



Style 4 - tagging and identity

## Touch counters

---

Tags track physical objects

- Link them to computer information

TouchCounters

- sense activity through magnetic, acceleration, and infrared sensors,
- indicate their status on bright LED displays.
- networked to a web server that generates use histograms for each object.



*Extracted from Tangible Media Group web site*

Style 4 - tagging and identity

## TouchCounters

---

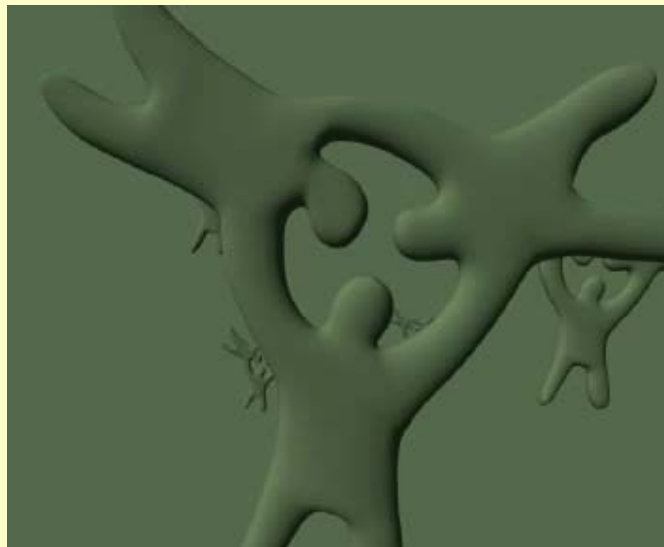


Source: *Tangible Media Group web site*

Style 4 - tagging and identity

## Philips Lime

---



From the *Philips Lime Video CD*

Style 5

## Attentive User Interfaces

technology that doesn't bug you when you're busy



Source: Roel Vertegaal, Queens U.

Style 5 – attentive user interface

## Aura Mirror



Source: Roel Vertegaal, Queens U.



Style 5 – attentive user interface

## Eye Phone

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Source: Roel Vertegaal, Queens U.

Style 5 – attentive user interface

## Attentive Office Cubicle

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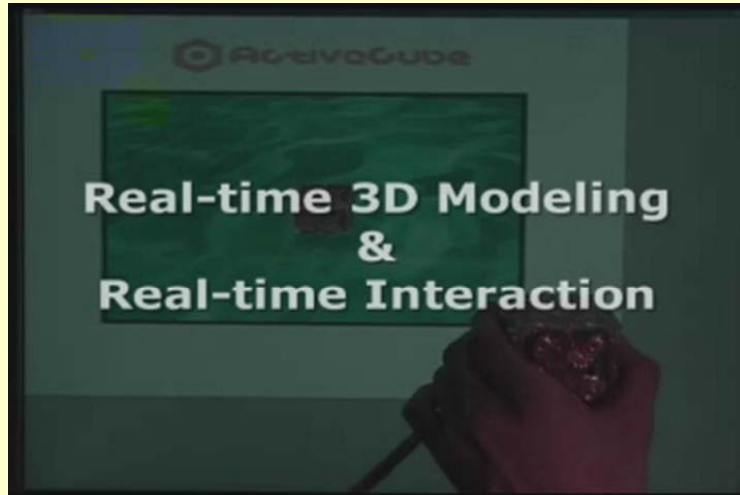
Source: Roel Vertegaal, Queens U.

Style 6

## **Geometric Modeling**

---

Model geometry on the screen



Source: Osaka University Human Interface Engineering Lab: [www-human.lst.osaka-u.ac.jp/ActiveCube/](http://www-human.lst.osaka-u.ac.jp/ActiveCube/)

Style 6 - geometric modeling

## **HandScape**

---

digitizes field measurements and visualizes them on a display



Source: Tangible Media Group web site

Style 7

## Collaborative interactions

### Bench

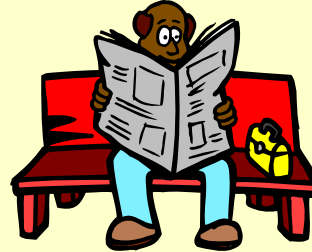
...two cold steel benches located in different cities.

When a person sits on one of these benches, a corresponding position on the other bench warms, and a bi-directional sound channel is opened.

At the other location, after feeling the bench for "body heat," another person can decide to make contact by sitting near the warmth.

Initially the sound channel is distorted, but as the second party lingers, the audio channel clears.

--summarized by Ishii and Ullmer



Anthony Dunne and Fiona Raby at the RCA

ambient displays

## Personal Ambient Display

Small, physical devices worn to display information to a person in a subtle, persistent, and private manner.

Ambient information is displayed solely through tactile modalities such as heating and cooling, movement and vibration, and change of shape.



Extracted from Tangible Media Group web site

Style 7 - Collaborative interactions

## Digital but Physical Surrogates



Style 7 - Collaborative interactions

## Digital but Physical Surrogates



Source: Saul Greenberg, ACM CHI 99 Video Proceedings



Style 7 - Collaborative Interactions

## Privacy preserving media space



Style 7 - collaborative interaction

## InTouch



Source: Tangible Media Group web site



Style 8

## **Aging in place / Health**

---

Physical objects monitor others



*keeping an eye out for family members*

Source: Georgia Tech. Everyday Computing Lab web site (Rowan and Mynatt)

Style 9

## **Roomware i-land**

---

Computer-augmented room elements

- like doors, walls, furniture (e.g. tables and chairs) with integrated information and communication technology.



From the GMD Darmstadt web site on I-Land

Style 9

## **Roomware** i-land

---

### Dynawall



*From the GMD Darmstadt web site on I-Land*

Style 9

## **Roomware** i-land

---

### CommChair



*From the GMD Darmstadt web site on I-Land*

Style 9

## Roomware i-land

---

### ConnecTable

By moving multiple ConnecTables together, they can be arranged to form a large display area. Integrated sensors measure the distance between the ConnecTables and initiate the automatic coupling of the displays



*From the GMD Darmstadt web site on I-Land*

Style 9

## Roomware i-land

---

**i-LAND**

an interactive landscape  
for creativity and innovation

ACM CHI'99 Video Proceedings

Style 10

## Toys and Games

---



Source: Nancy Lopez; Saul Greenberg Phidget Project Collection

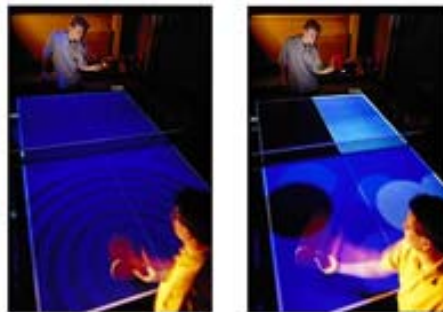
Style 10 Toys and Games

## PingPong Plus

---

features a "reactive table" that incorporates sensing, sound, and projection technologies.

Projectors display patterns of light and shadow on the table; bouncing balls leave images of rippling water; and the rhythm of play drives accompanying music and visuals.



Photos: Webb Chappell

Extracted from Tangible Media Group web site

Style 10 Toys and Games

## PingPong Plus

---



*Extracted from Tangible Media Group web site*

Style 10

## Musical devices

---



*Source: Olive Au; Saul Greenberg Phidget Project Collection*

Style 10

## Musical devices

---



Source: Phidgets USA web site

Style 11

## Theatre

---



**The Rusty Barnacle**  
Kevin Foster

Source: Kevin Foster; Saul Greenberg Phidget Project Collection

Style 12

## **Music players**

---



Source: Rob Diaz-Marino: Saul Greenberg Phidget Project Collection

Style n...

## **Other opportunities**

---

Anywhere you see something physical, ask:

what are the opportunities for repurposing this into a physical user interface?



## Outline

## Styles of use

- ambient displays
- foreground interaction
- physical controls
- tagging and identity
- attentive user interfaces
- ...

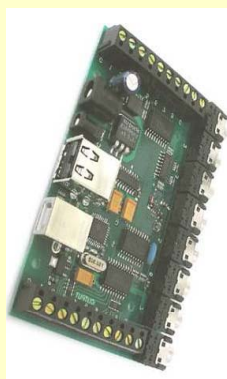
## How to build them

- building blocks
- hardware / software platforms
- case study: phidgets

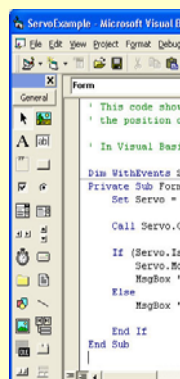
## How to build them



**building  
blocks**



- + hardware design



+ **software**



+ design



building blocks

## Digital inputs - switches



Rocker



Toggle



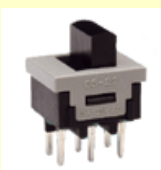
Push button



Push-Pull



Rotary



Slide



Tactile



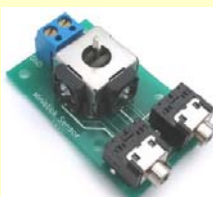
Keylock

building blocks

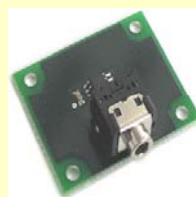
## Analog inputs – manual sensors



Force



Mini-joystick



Capacitive



Accelerometer



single-turn



multi-turn



encoder



slider

### Potentiometers

building blocks

## Analog inputs – manual sensors



Bend



Force



Tilt



gyroscope

building blocks

## Analog inputs – environmental sensors



Light



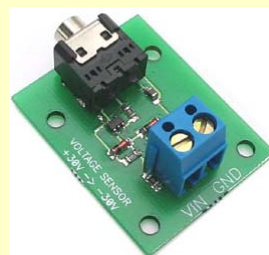
Temperature



Pressure



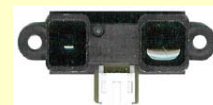
Motion



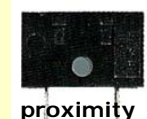
Voltage



Weight



rangefinder



proximity

Distance

building blocks

## Custom inputs - identification



RFID tags and antenna



Bar code scanner



Fingerprint reader

building blocks

## Digital outputs – low power

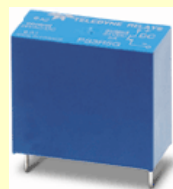


lamps



LEDs

### Lights



Relays



Solenoids

building blocks

## Analog outputs: Motors



Position: 0-180°  
**Servo**



Rotate by steps:  $\pm x^\circ$   
**Stepper**



Speed  
**DC Motor**

building blocks

## Character and image output: Displays



**Text LCD**



**Graphics (not yet)**



**Numeric-alpha**

building blocks

## Others...

---

### Outputs

- tactons (vibration)
- scent
- heat
- sound

### Inputs

- sound activated switches
- wireless switches
- PH sensor
- humidity sensor
- thermopile (temperature at a distance)
- cameras (images / motion / activation) ...



hardware

## PIC Micro-controller

---

Single programmable chip computer with:

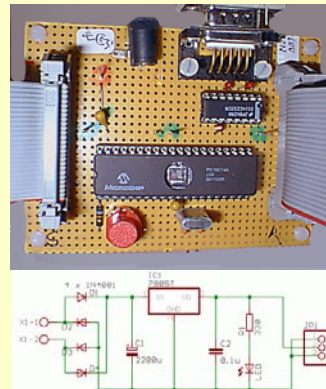
- CPU, RAM, ROM, I/O, serial/parallel ports, A/D and D/A converters

Need to know:

- basic circuit design (maybe)
- basic electronics
  - resistor, capacitor, diodes, transistors...
- micro-controller details
- low level programming
- networking ...

Flexible, but

- high learning curve
- excessive time in low level details
- serial



Products: [microchip.com](http://microchip.com)

hardware

## Basic Stamp

### Pre-built boards

- Pic microcontroller
- pre-wired circuits and connectors
- boards designed for different uses

### Need to know

- electronic components + circuitry
- PBasic language: stamp-specific instruction set

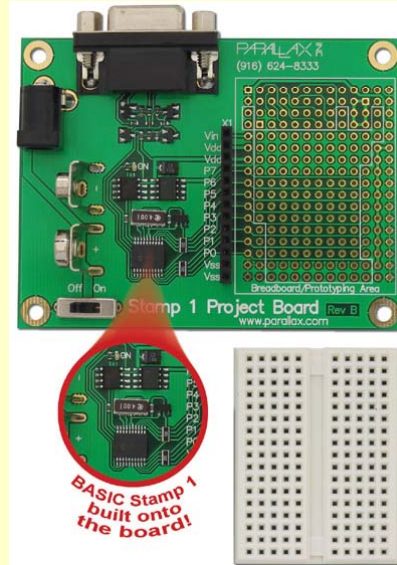
### Still flexible, but

- learning curve still there
- time in low level details

### Tradeoff

- learning vs. performance

Products: [parallax.com](http://parallax.com)



hardware

## Motes

### Wireless sensor boards

- Smart Dust Project (Berkeley)
- battery-powered processor/radio board with tinyOS
- stackable daughter boards for sensing
- talks to
  - other motes (programming board: USB to computer)
  - stargate gateway: complete palm-sized linux system

### Need to know

- TinyOS libraries / NesC language
- can create own custom daughter boards, but...

### Potentially good design flexibility, but

- high software learning curve
- very hard to program

see also SmartIts (Europe)

Products: [xbow.com](http://xbow.com)

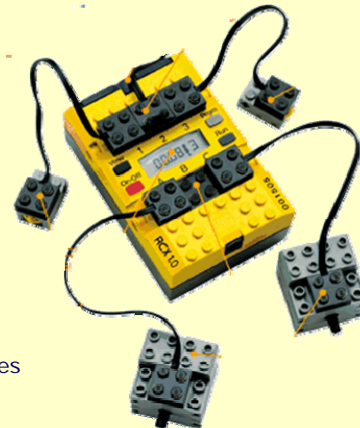


hardware

## Lego Mindstorms

### Programmable brick

- proprietary RCX microcontroller with infrared communication
- reasonable range of input/output devices
- Lego building blocks
- robotics (downloadable code)
- children's programming language *but*
  - well-defined SDK
  - 3<sup>rd</sup> party access from standard languages



### Need to know

- SDK / language

### Low flexibility

- limited input/output (3+3), limited i/o devices
- expensive for basic set, plus add-ons

Products: [mindstorms.lego.com](http://mindstorms.lego.com)

hardware

## Off the shelf devices

### Fixed function and form

- X10 smart home devices
- hacked products



### Need to know

- protocol

### Low design potential

- fixed form factor
- repurposed functionality





hardware

## **Phidgets *and* Making Things**

### Hardware as software components

- dedicated devices
- some plug and play electronics
- under direct computer control
- well-defined component-based software
  - interface via APIs, objects, and/or widgets

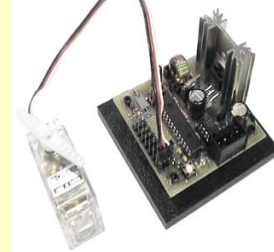
### Need to know

- high level programming language
- software API documentation

### Design flexibility vs. electronic flexibility

- very low learning curve
- design by combining and varying
- time in conceptual design, not electronics

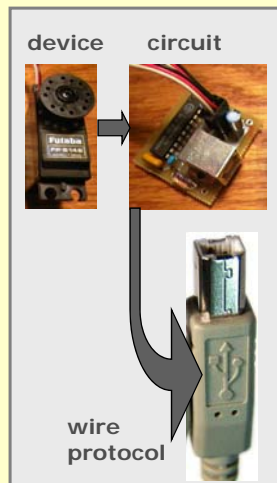
Products: [phidgets.com](http://phidgets.com), [makingthings.com](http://makingthings.com)



case study

## **Phidget architecture**

### Hardware

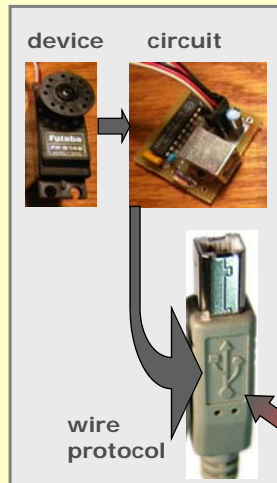




case study

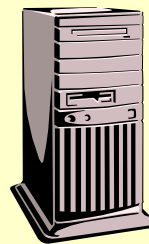
## Phidget architecture

### Hardware



### Software

wire protocol

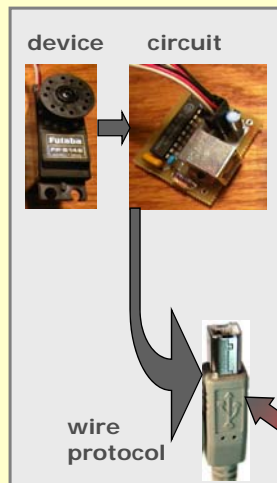


communication layer

case study

## Phidget architecture

### Hardware



### Software

#### phidgetManager

##### Events

pm.OnAttach(phidget)  
pm.OnDetach(phidget)

##### Properties

pm.DeviceType  
pm.SerialNumber...

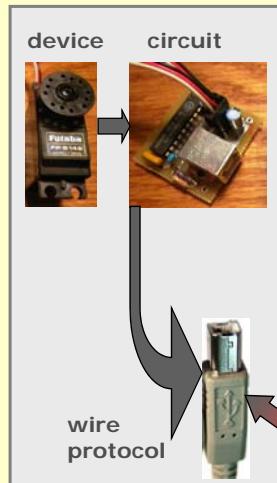


communication layer

case study

## Phidget architecture

### Hardware



### Software

#### phidgetServo

Events  
servo.OnPositionChanged

Properties  
servo.MotorPosition=90

#### phidgetManager

Events  
pm.OnAttach(phidget)  
pm.OnDetach(phidget)

Properties  
pm.DeviceType  
pm.SerialNumber...

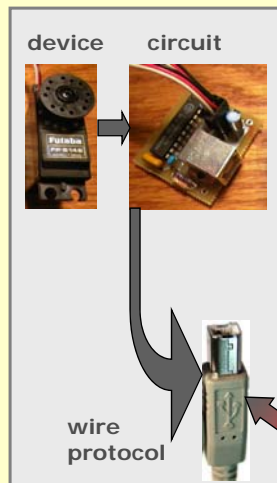
#### communication layer



case study

## Phidget architecture

### Hardware



### Software

#### phidgetServo skin



#### phidgetServo

Events  
servo.OnPositionChanged

Properties  
servo.MotorPosition=90

#### phidgetManager

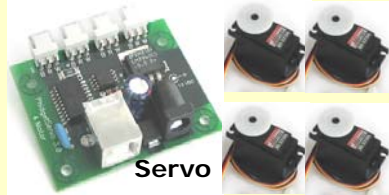
Events  
pm.OnAttach(phidget)  
pm.OnDetach(phidget)

Properties  
pm.DeviceType  
pm.SerialNumber...

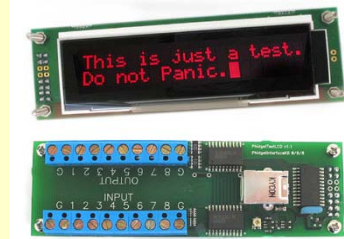
#### communication layer

case study

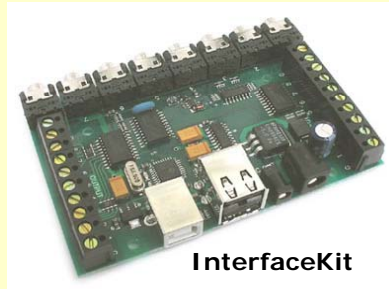
## Phidget demonstration



Servo



Displays



InterfaceKit



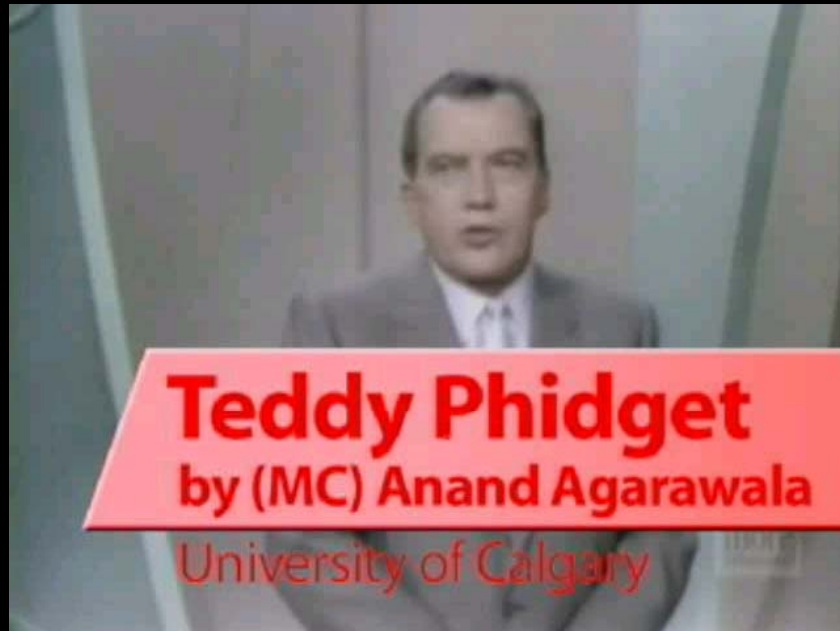
RFID Reader

case study

## Design



One last video...



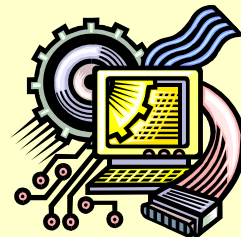
## Physical User Interfaces

What they are and how to build them

You should now know

- various genres and opportunities of physical user interfaces
- basic hardware building blocks available to you
- how to get started building your own physical user interfaces

You too can rapidly prototype physical user interfaces



hardware

## Lego Mindstorms

### Programmable brick

- proprietary RCX microcontroller with infrared communication
- reasonable range of input/output devices
- Lego building blocks
- robotics (downloadable code)
- children's programming language *but*
  - well-defined SDK
  - 3<sup>rd</sup> party access from standard languages

### Need to know

- SDK / language

### Great for robotics

- limited input/output (3+3)
- expensive for basic set, plus add-ons



[www.mastincrosbie.com/mark/lego/images/grabberarm1.jpg](http://www.mastincrosbie.com/mark/lego/images/grabberarm1.jpg)

**Products:** [mindstorms.lego.com](http://mindstorms.lego.com)