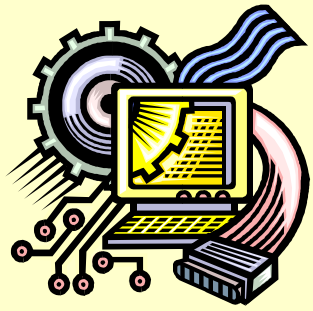
# Physical User Interfaces

**What they are and how to build them**

**Saul Greenberg**
**University of Calgary**
**CPSC 581**



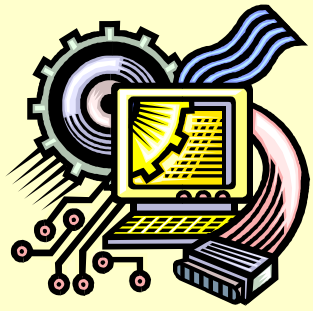
## New disciplines and genres of computing

- 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

*Modified from Mark Weiser's UbiqCom web site*

## Physical Things

People

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

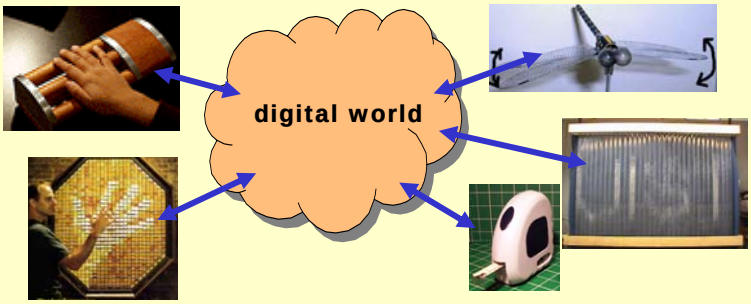
## Physical User Interfaces – Why?

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

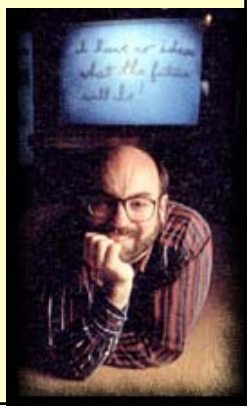
- **appliance-like**: designed for particular context and uses
- **composition**: microcontroller, actuators, sensors, motors…
- **connectivity**: with digital computers and information




## 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."

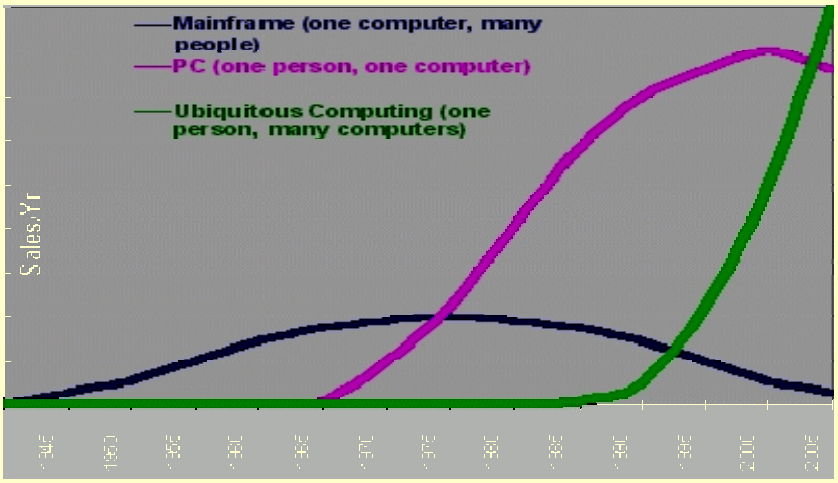


### invisible

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

*Source: Mark Weiser's UbiqCom web site*

## Ubicomp Technology Trends




*Source: Mark Weiser's UbiqCom 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"

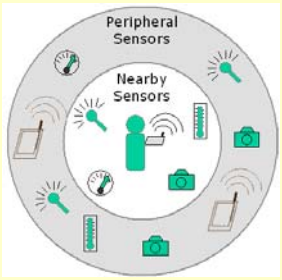
- from painted bits to tangible bits
- **input:** grasp and manipulate
- **output:** change physical properties of object

*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 UbiqCom 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 UbiqCom 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 UbiqCom web site*

Style 1 - ambient displays

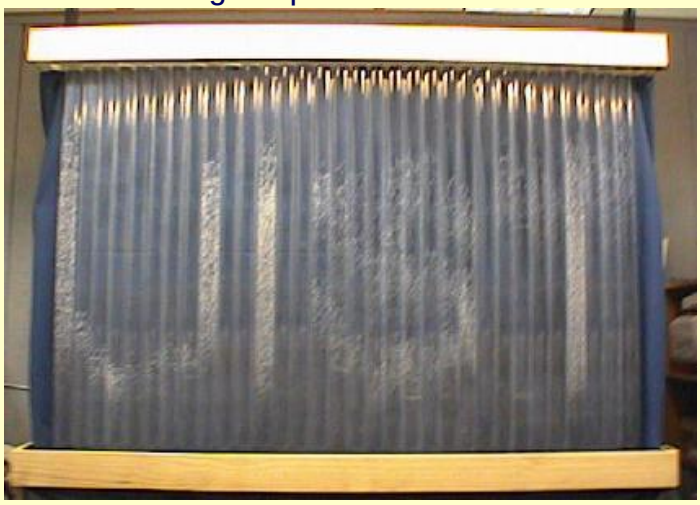
## Ambient Room


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

Style 1 - ambient displays

## Information Perculator

bubbles of digital patterns



*Source: Heiner, Hudson & Tanaka*

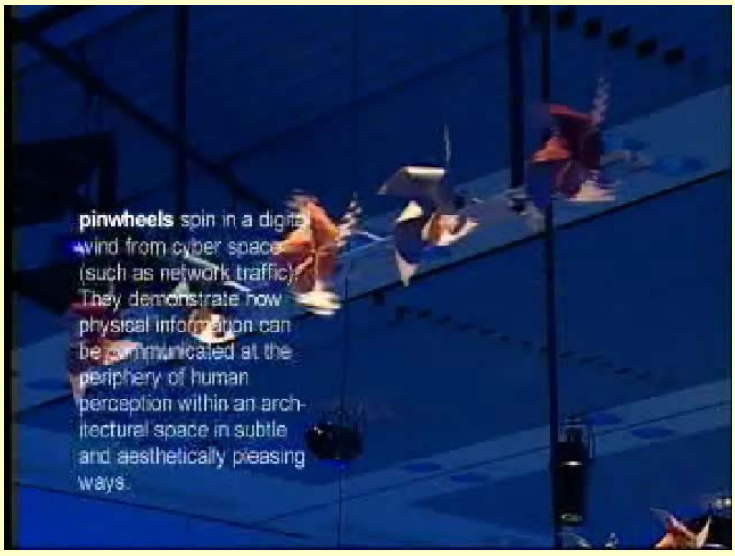
Style 1 - ambient displays

## 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

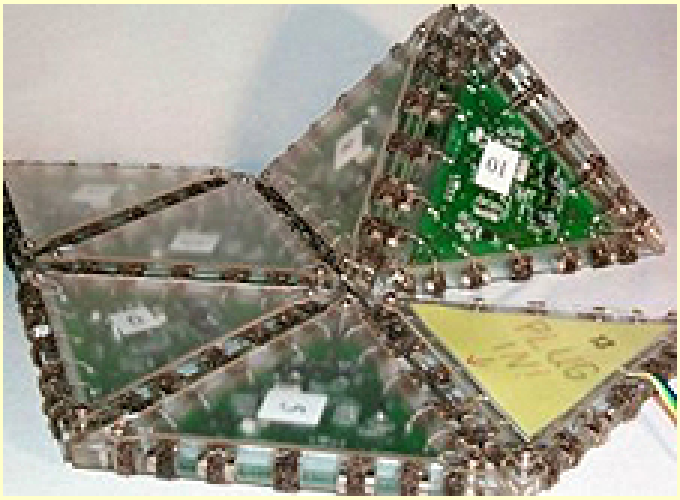
physical expression:

- conscious intentional interactions
- grasping, direct feedback…


Style 2 - foreground interaction

## Triangles

Connecting triangles create a digital story

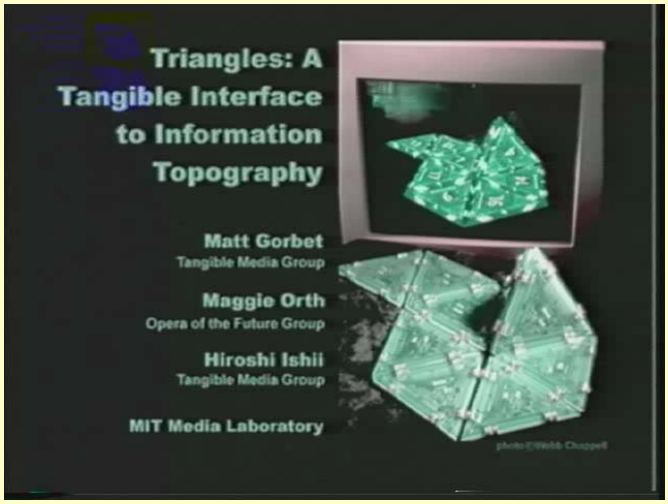


*Source: Tangible Media Group web site*

Style 2 - foreground interaction

## Triangles

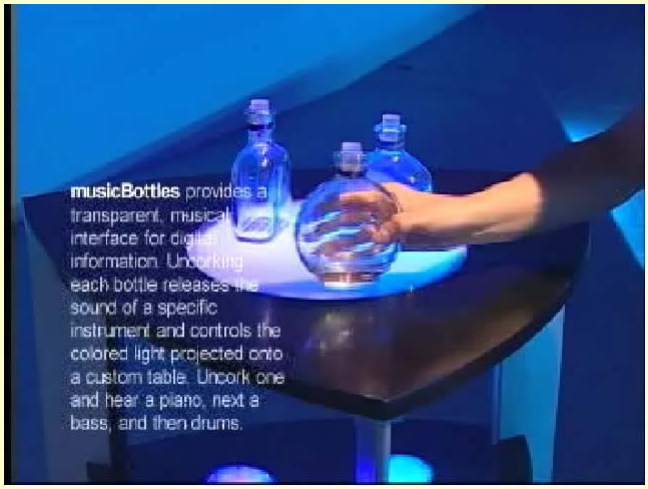
Connecting triangles create a digital story




*Source: Tangible Media Group web site*

Style 2 - foreground interaction

## Music Bottles



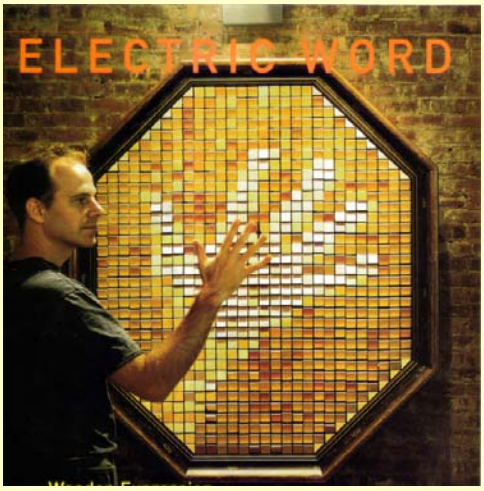

movement and uncorking of the bottles controls digital contents

*Source: Tangible Media Group web site*

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


*Source: Sydney Fels, UBC*

Style 3

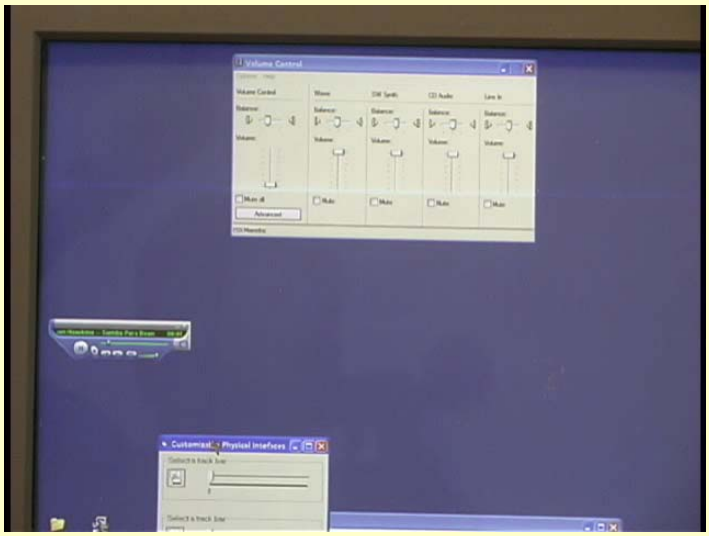
## Physical controls to GUIs

richer physical interface


*Source: CHI-83*

Style 3 - physical controls

## Customizable User Interfaces



Source: Saul Greenberg, UIST 2002

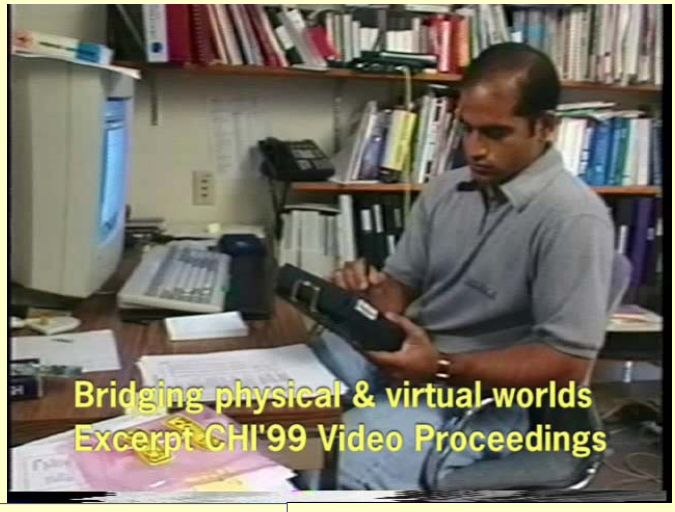
Style 3 - physical controls

## Manipulative User Interfaces

Style 4

## Tagging and Identity

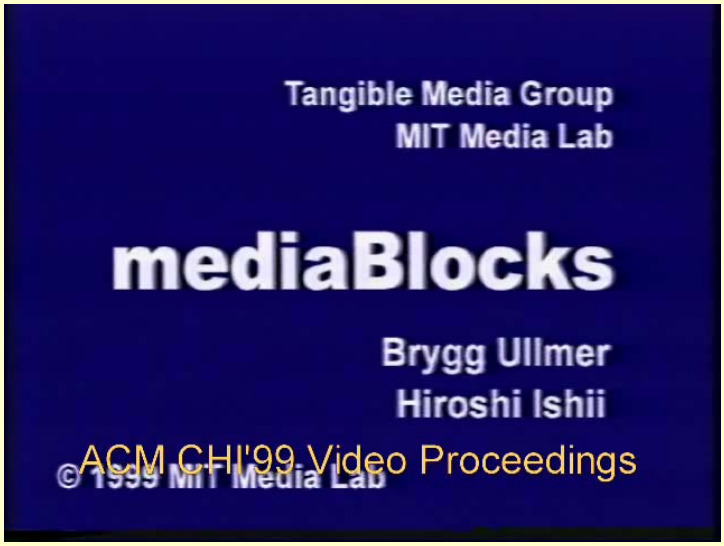
Tags identify and link physical objects to computer information




*Source: Xerox PARC, CHI'00 Video Proceedings*

Style 4 - tagging and identity

## mediaBlocks




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

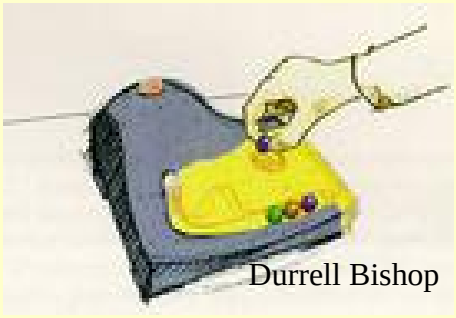
Style 4 - tagging and identity

## 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*

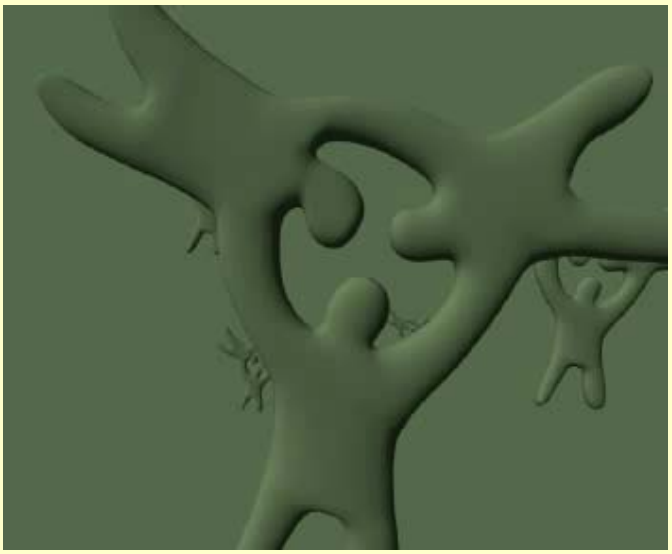
Style 4 - tagging and identity

## 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

*Source: Roel Vertegaal, Queens U.*

Style 5 – attentive user interface

## Attentive Office Cubicle

*Source: Roel Vertegaal, Queens U.*

Style 6

## Geometric Modeling

Model geometry on the screen


*Source: Osaka University Human Interface Engineering Lab:www-human.ist.osaka-u.ac.jp/ActiveCube/*

Style 6 - geometric modeling

## HandScape

digitizes field measurements a visualizes them on a display


*Source: Tangible Media Group web site*

Style 7

## Collaborative interactions

### Bench

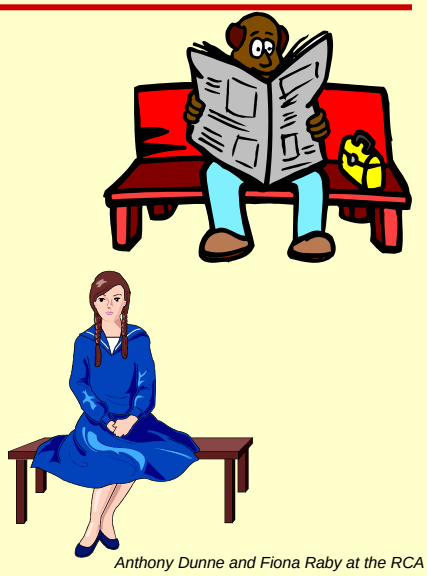
…two cold steel benches located in different cities.

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

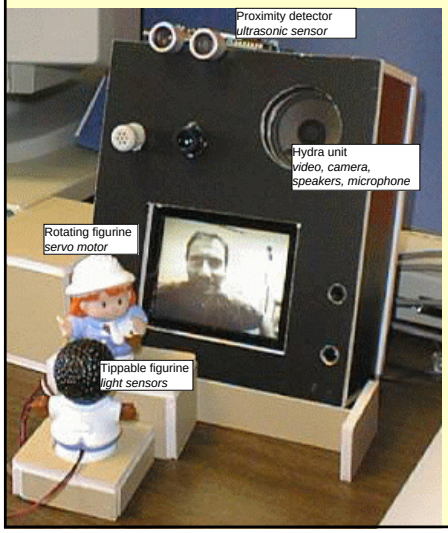
Small, physical devices worn to display information to a person in a subtle, persistent, and private manner.

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

Style 10

## Toys and Games

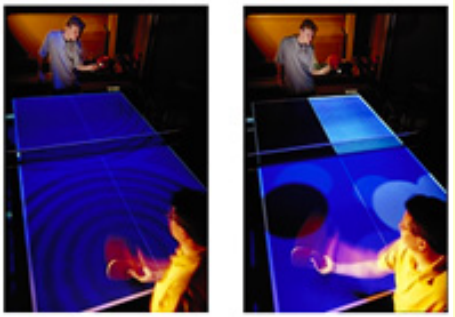

*Source: Nancy Lopez; Saul Greenberg Phidget Project Collection*

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.

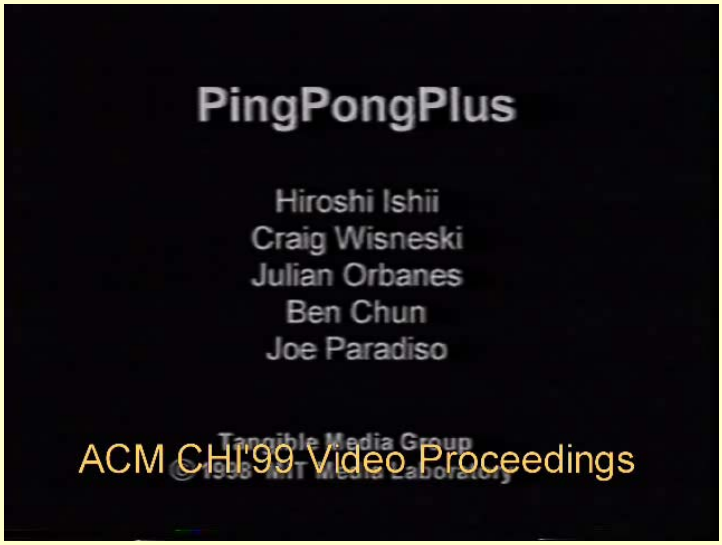


*Photos: Webb Chappell*

*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


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

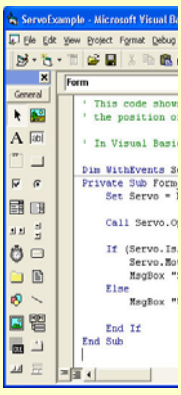
Styles of use

- 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

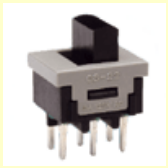

Rocker


Toggle


Push button


Push-Pull


Rotary


Slide

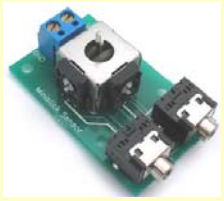

Tactile


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

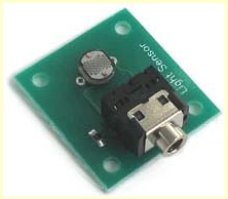
Force

Tilt


gyroscope

building blocks

## Analog inputs – environmental sensors



Light

Temperature

Pressure

Motion


Voltage

Weight

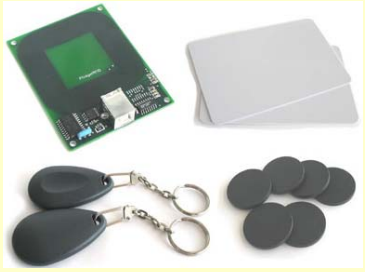
rangefinder

proximity

Distance

building blocks

## Custom inputs - identification



RFID tags and antenna


Bar code scanner


Fingerprint reader

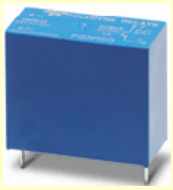
building blocks

## Digital outputs – low power

lamps

LEDs

Lights



Relays

Solenoids

building blocks

## Analog outputs: Motors

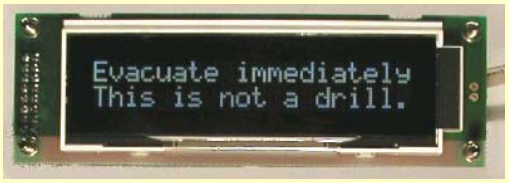
Position: 0-180º
**Servo**

Rotate by steps: +/- xº
**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

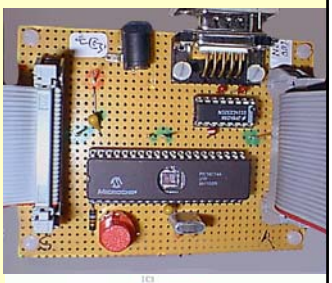
## PIC Micro-controller

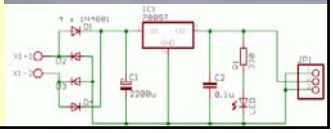
### Single programmable chip computer with:

- 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***

hardware

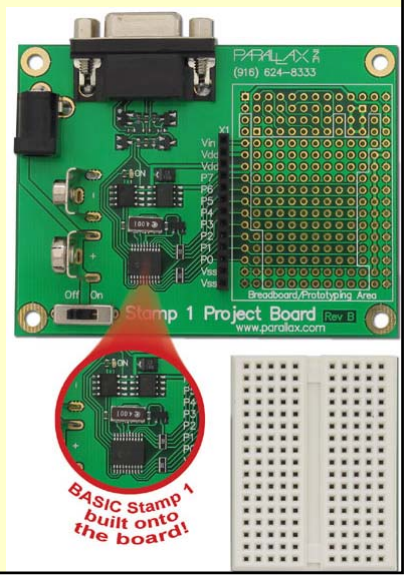
## Basic Stamp

Pre-built boards
- Pic microcontroler
- 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***

hardware

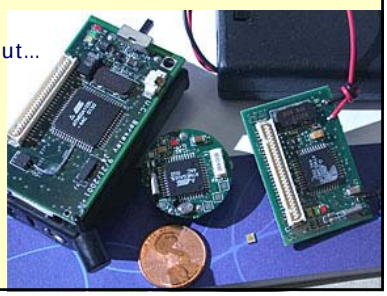
## Motes

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)



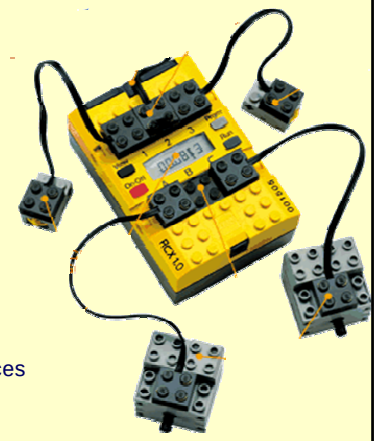
***Products: xbow.com***

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
  - 3rd 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***

hardware

## Off the shelf devices

### Fixed function and form

- X10 smart home devices
- hacked products


### Need to know

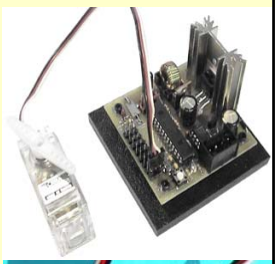
- protocol

### 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

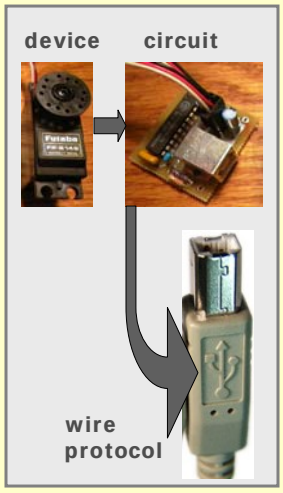
- very low learning curve
- design by combining and varying
- time in conceptual design, not electronics

***Products: phidgets.com, makingthings.com***

case study

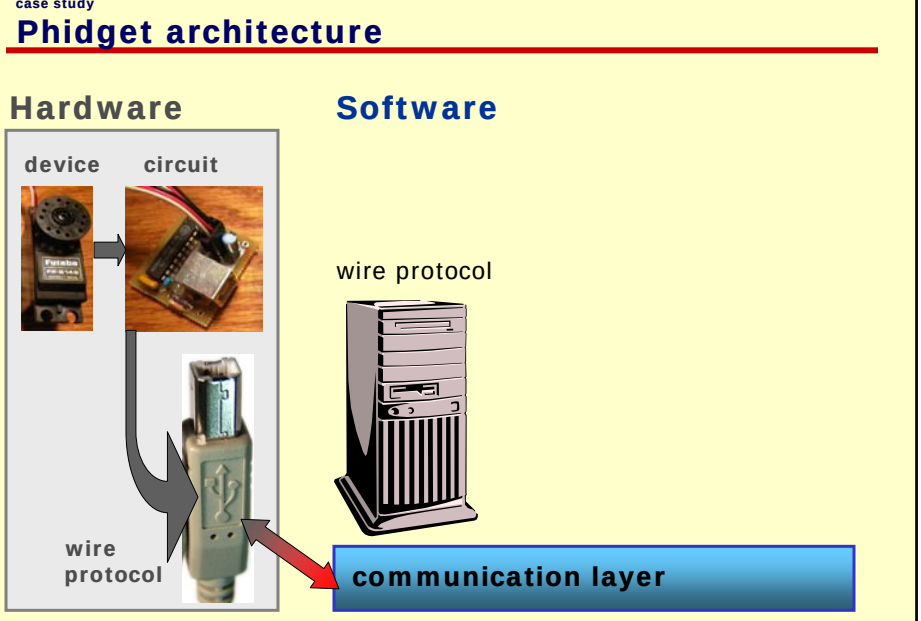
## Phidget architecture

### Hardware



case study

## Phidget architecture




case study

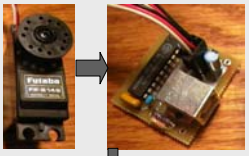
## Phidget architecture

case study

## Phidget architecture

### Hardware

device circuit



wire protocol

### Software

**phidgetServo**

| Events | Properties |
|---|---|
| servo.OnPositionChanged | servo.MotorPosition=90 |

**phidgetManager**

| Events | Properties |
|---|---|
| pm.OnAttach(phidget) | pm.DeviceType |
| pm.OnDetach(phidget) | pm.SerialNumber... |

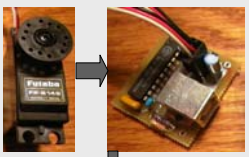
**communication layer**

case study

## Phidget architecture

### Hardware

device circuit



wire protocol

### Software

**phidgetServo skin**


**phidgetServo**

| Events | Properties |
|---|---|
| servo.OnPositionChanged | servo.MotorPosition=90 |

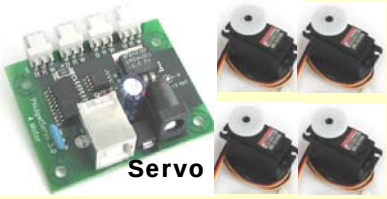
**phidgetManager**

| Events | Properties |
|---|---|
| pm.OnAttach(phidget) | pm.DeviceType |
| pm.OnDetach(phidget) | pm.SerialNumber... |

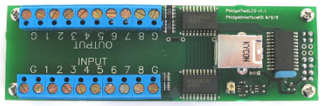
**communication layer**

case study

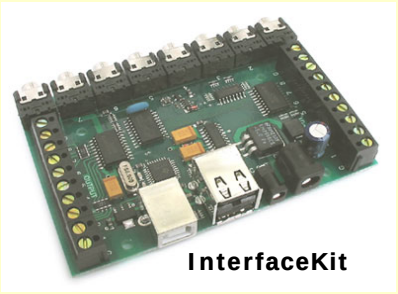
## Phidget demonstration



Servo

Displays



InterfaceKit

RFID Reader

case study

## Design

One last video…

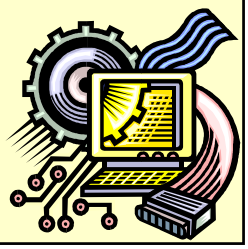

# Physical User Interfaces

**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

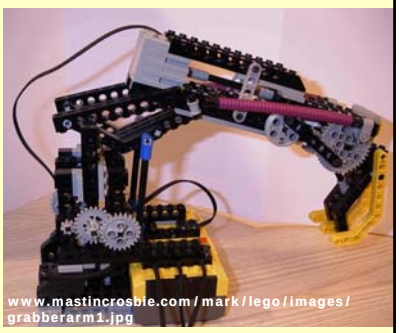


hardware

# 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
  - 3rd party access from standard languages



www.mastincrosbie.com/mark/lego/images/grabberarm1.jpg

## Need to know

- SDK / language

## Great for robotics

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

***Products: mindstorms.lego.com***