

Authoring Sensor-Based Interactions by Demonstration

with Direct Manipulation and Pattern Recognition

*Björn Hartmann, Leith Abdulla
Manas Mittal, Scott R. Klemmer*



How would you prototype...



...a workout monitoring system?

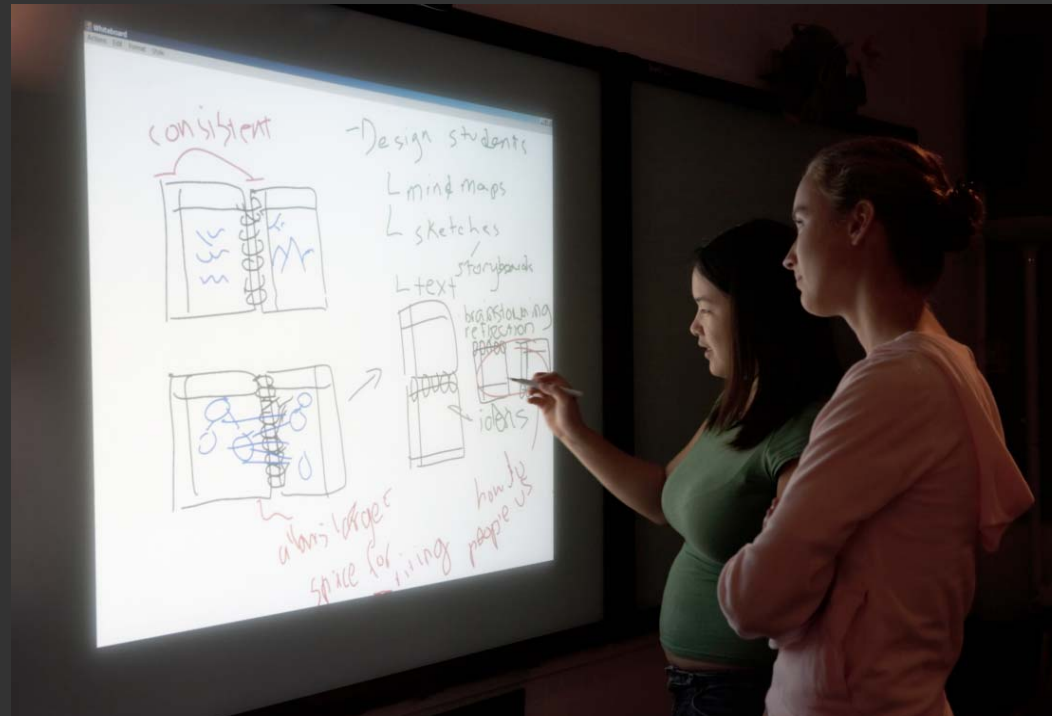
How would you explore...



...motion-based game controllers?

[Nintendo]

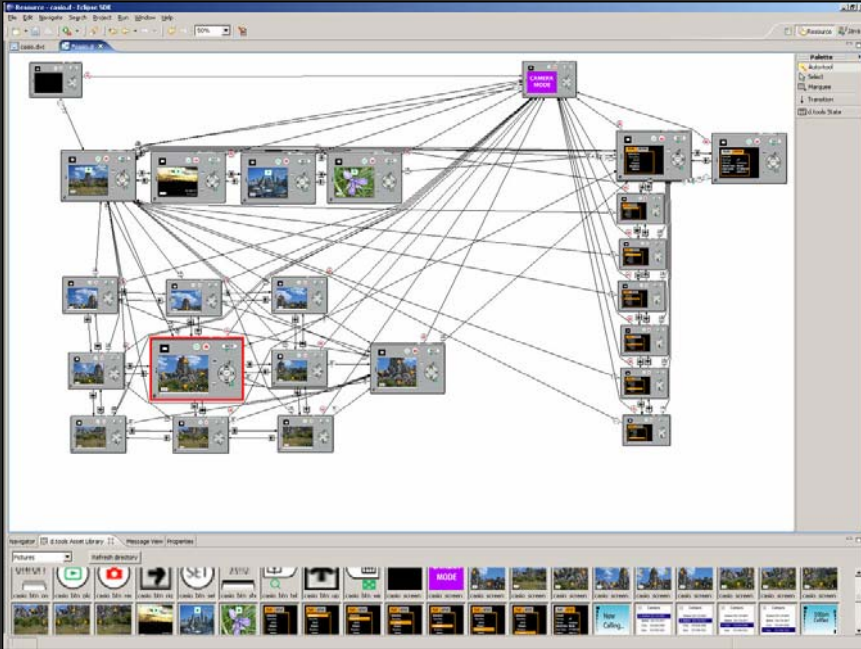
How would you build...



...a proximity-aware whiteboard?

Sensor-based Interaction Design

d.tools



[Hartmann et al., UIST '06]



d.Tools Student Project



d.tools



Designing Sensor-based Interactions

PROTOTYPE APPLICATION LOGIC

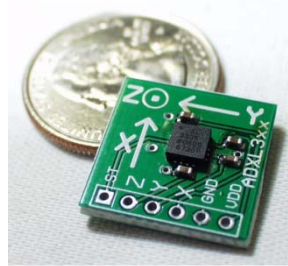


**SPECIFY RELATIONSHIP
BETWEEN SENSOR DATA
AND APPLICATION LOGIC**

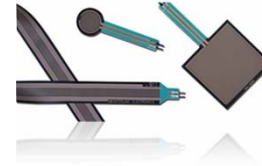
**PROVIDE SOFTWARE ABSTRACTION
FOR HARDWARE**



Types of Sensors



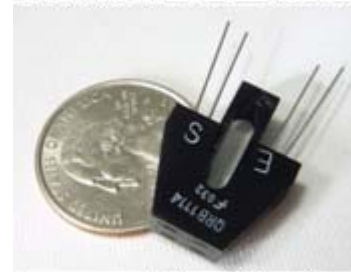
Accelerometers



Force Sensitive Resistors



IR/Ultrasonic Rangefinders



Phototransistors



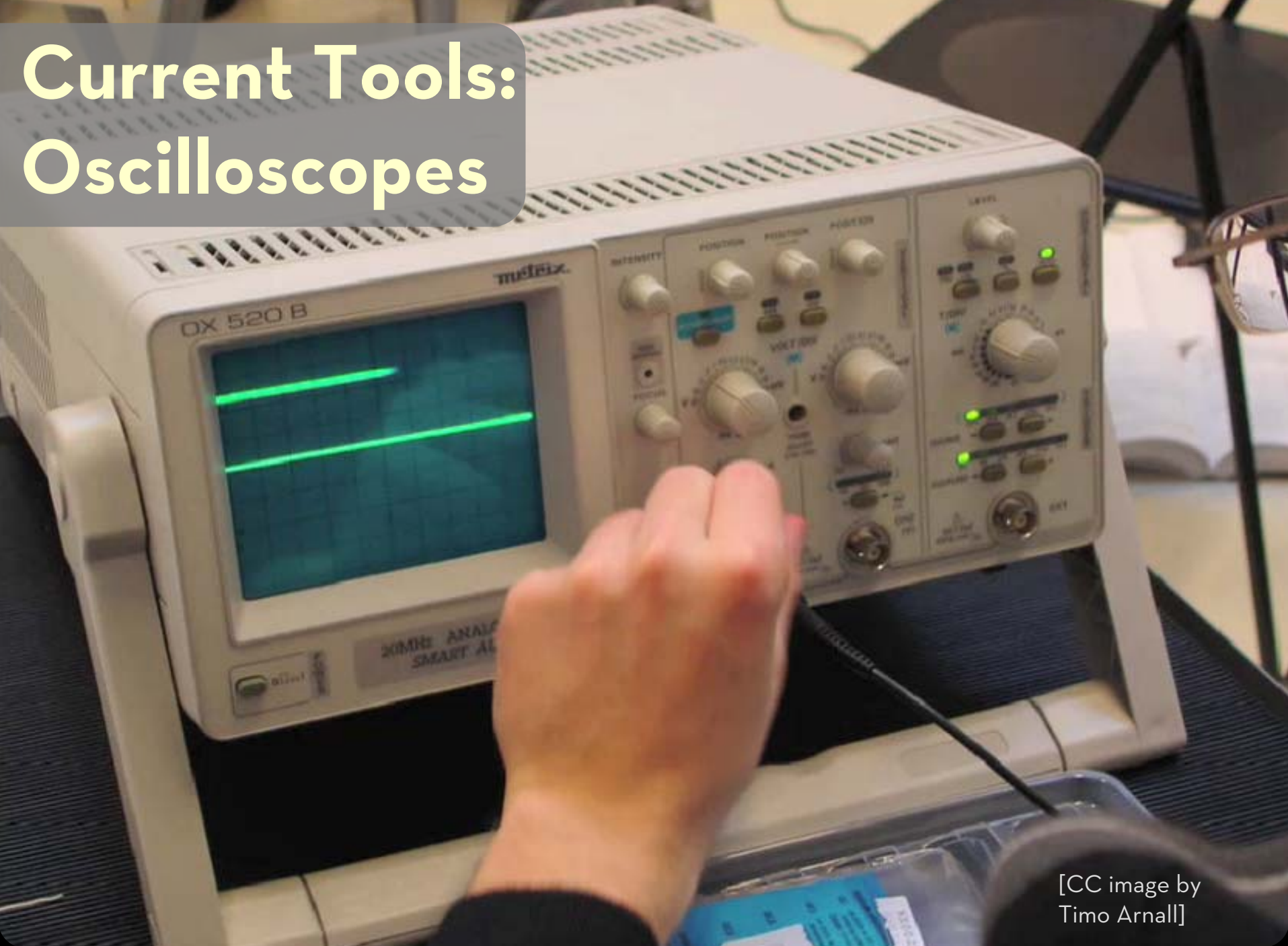
RFID

Discrete

Continuous

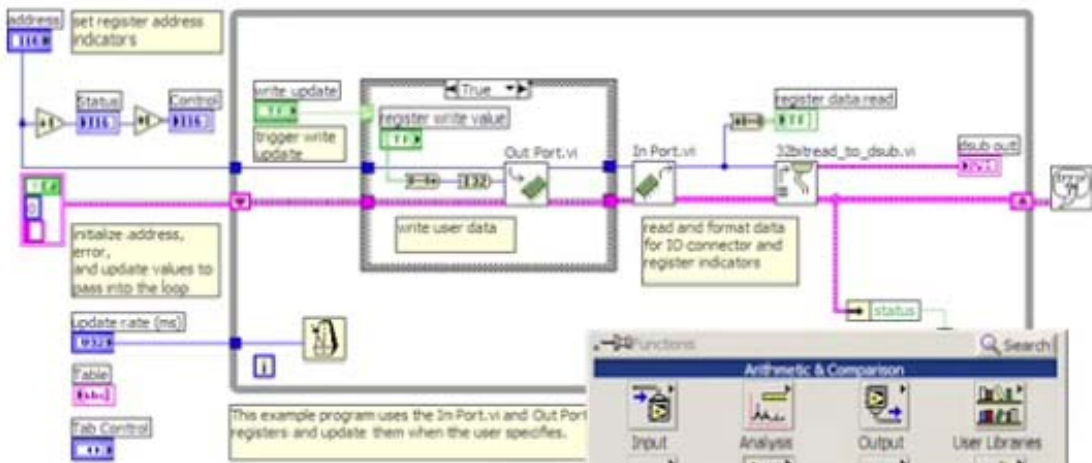
Categorical

Current Tools: Oscilloscopes



[CC image by
Timo Arnall]

Current Tools: LabView



Functions palette showing categories: Arithmetic & Comparison, Input, Analysis, Output, User Libraries, Exec Ctrl, and Arith/Compert.

Express Numeric palette showing categories: Formula, Scale & Map, Time Domain, and Numeric.

Express Numeric Constants palette showing various mathematical operations and functions:

- Add, Subtract, Multiply, Divide
- Increment, Decrement
- Absolute Value, Round, Round To -Inf, Round To +Inf
- Square Root, Negate, Scale By 2ⁿ, Sign, Reciprocal
- Compound Arith, Trigonometric, Logarithmic
- Constants

Express Numeric Constants palette showing physical constants:

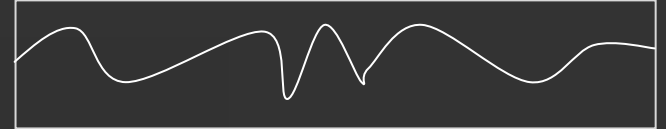
- Pi, 2*Pi, Pi/2, 1/Pi, ln Pi, -Infinity
- e, 1/e, log e, ln 10, ln 2, +Infinity
- Planck Const, Elem Charge, c, G, Avogadro, Rydberg, Molar Gas Const

LabView

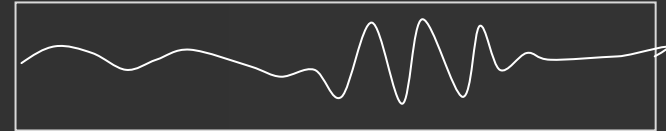
Representation Matters



Accelerometer X axis



Accelerometer Y axis



```
//detect accelerometer peaks

//read data sample
xVal[t++] = readA2DValue(xPin);

//look for changes in derivative
if(((xVal[t] - xVal[t-1]) >= 0
    && (xVal[t-1] - xVal[t-2]) < 0)
    ((xVal[t] - xVal[t-1]) < 0
    && (xVal[t-1] - xVal[t-2]) >= 0)
    //peak detected
    //send message
    oscSendMessageInt("/x/peak", 1);
} else {
    //no peak
}
```

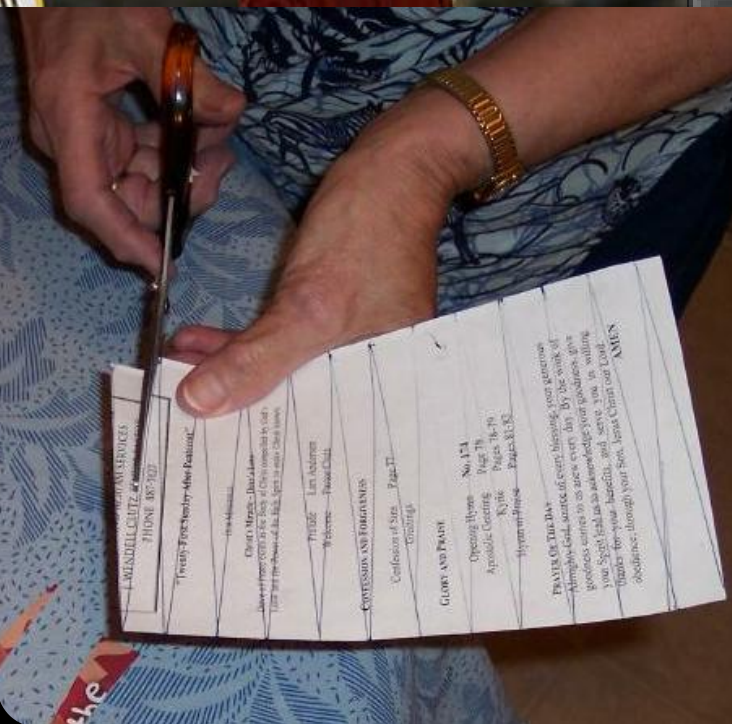
Idea: Programming by Demonstration



Idea: Programming by Demonstration



Tacit Knowledge



Crux: Generalization



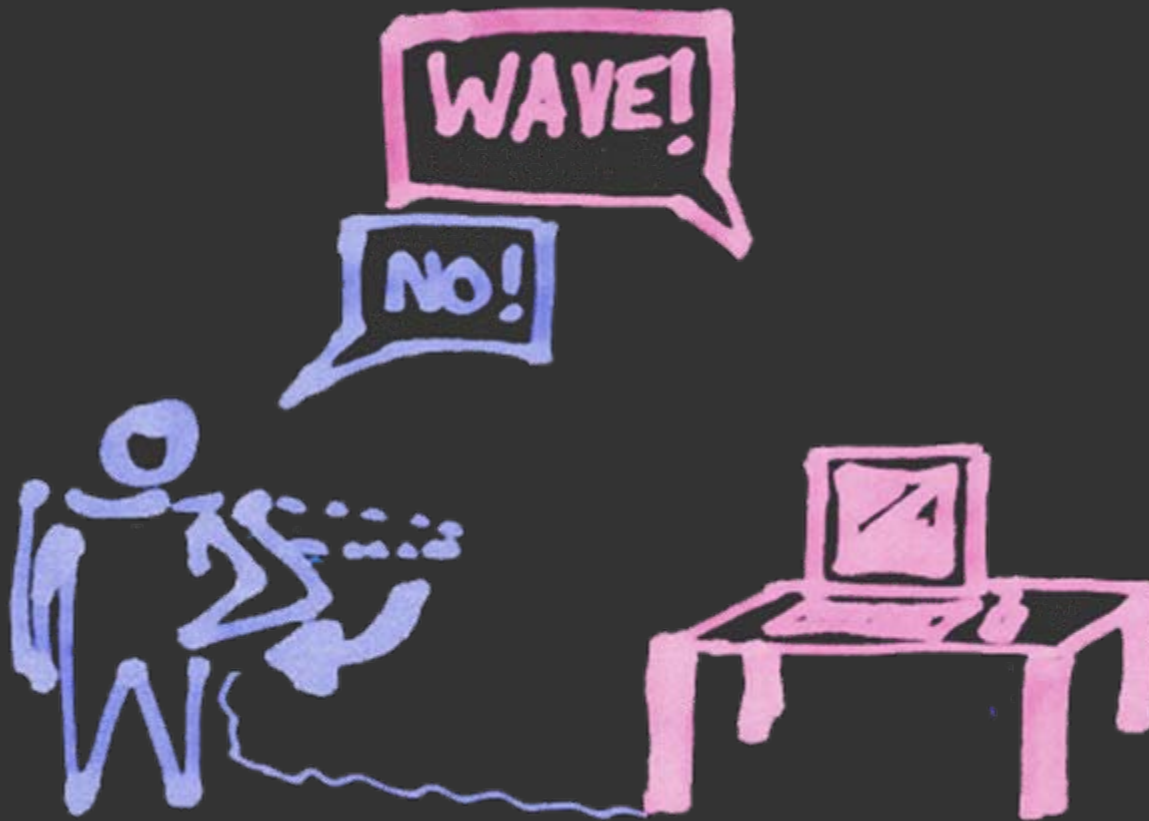
WAVE!



Crux: Generalization



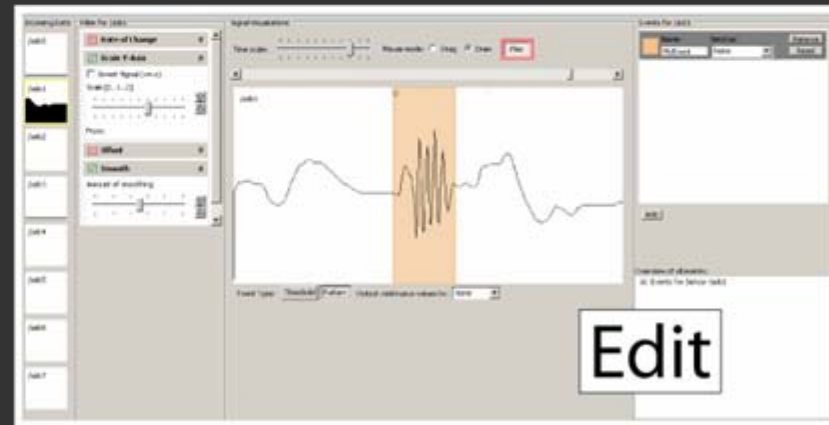
Crux: Generalization



Exemplar



Exemplar



Exemplar

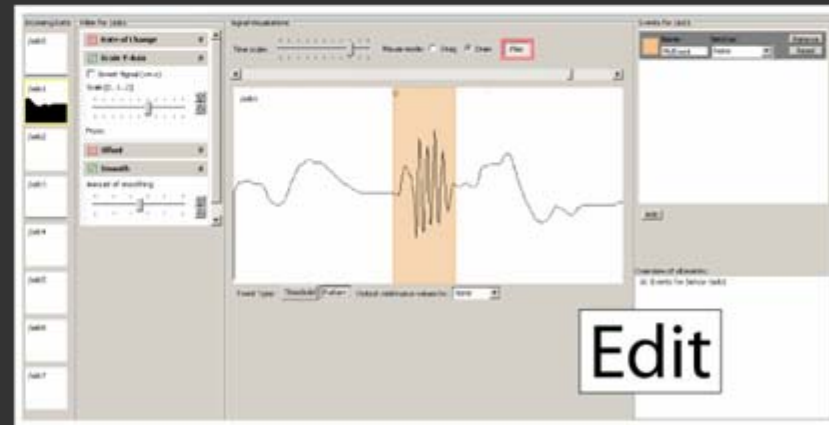
Demonstrate



Review



Edit



Exemplar

Demonstrate

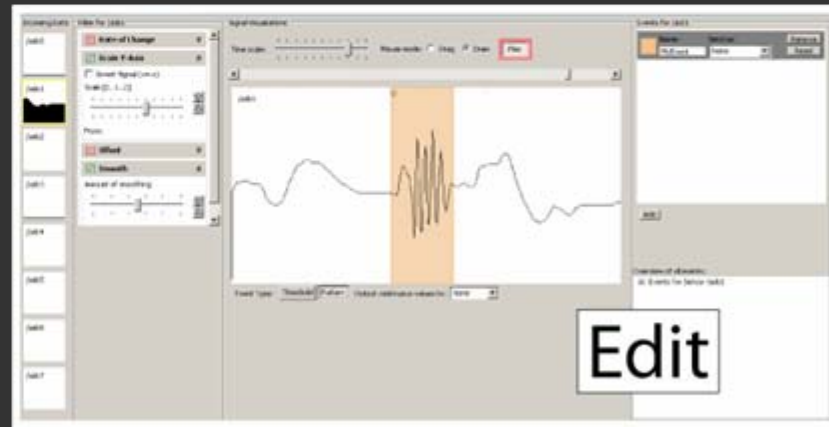


Export

Review



Edit



Exemplar UI

The image shows the Exemplar software interface. On the left, the 'Incoming Data' panel lists sensors /adc0 through /adc7. The 'Filter for /adc0' panel includes options for 'Scale Y-Axis' (checked), 'Invert Signal (x=-x)', 'Offset', and 'Smooth' (checked). The 'Signal Visualizations' panel features a 'Time scale' slider, 'Mouse mode' (Drag/Draw), a 'Play' button, and a waveform plot for /adc0. The plot shows a signal with a green shaded region and a horizontal line at 'min 0.15'. Below the plot are 'Event Type' (Threshold/Pattern) and 'Output continuous values to: None' options. On the right, the 'Events for /adc0' panel shows two event configurations: 'Bent' (Send as: /out1) and 'Extended' (Send as: /out3). An 'Overview of all events' panel at the bottom right lists events for sensors /adc0, /adc3, and /adc4.

Scale Y-Axis **Invert Signal (x=-x)**
Scale [0..1..2]
From: Center Offset
Smooth
Amount of smoothing

Time scale: Mouse mode: Drag Draw **Play**

min 0.15 | H | timeout

Event Type: Output continuous values to:

Events for /adc0

Name	Send as	Remove	Reset
Bent	/out1	<input type="button" value="Remove"/>	<input type="button" value="Reset"/>
Extended	/out3	<input type="button" value="Remove"/>	<input type="button" value="Reset"/>

Overview of all events:

- Events for Sensor /adc0
 - Event Bent - outputs to: /out1
 - Marked Region
 - Event Extended - outputs to: /out3
- Events for Sensor /adc3
 - Event TiltLeft - outputs to: /key/left
 - Event TiltRight - outputs to: /key/right
- Events for Sensor /adc4
 - Event Foot Pedal - outputs to: /key/enter

Exemplar UI

The image shows the Exemplar UI interface. On the left, the 'Incoming Data' panel lists channels /adc0 through /adc5. The /adc0 channel is highlighted with a red box. The main area is divided into 'Filter for /adc0' and 'Signal Visualizations'.

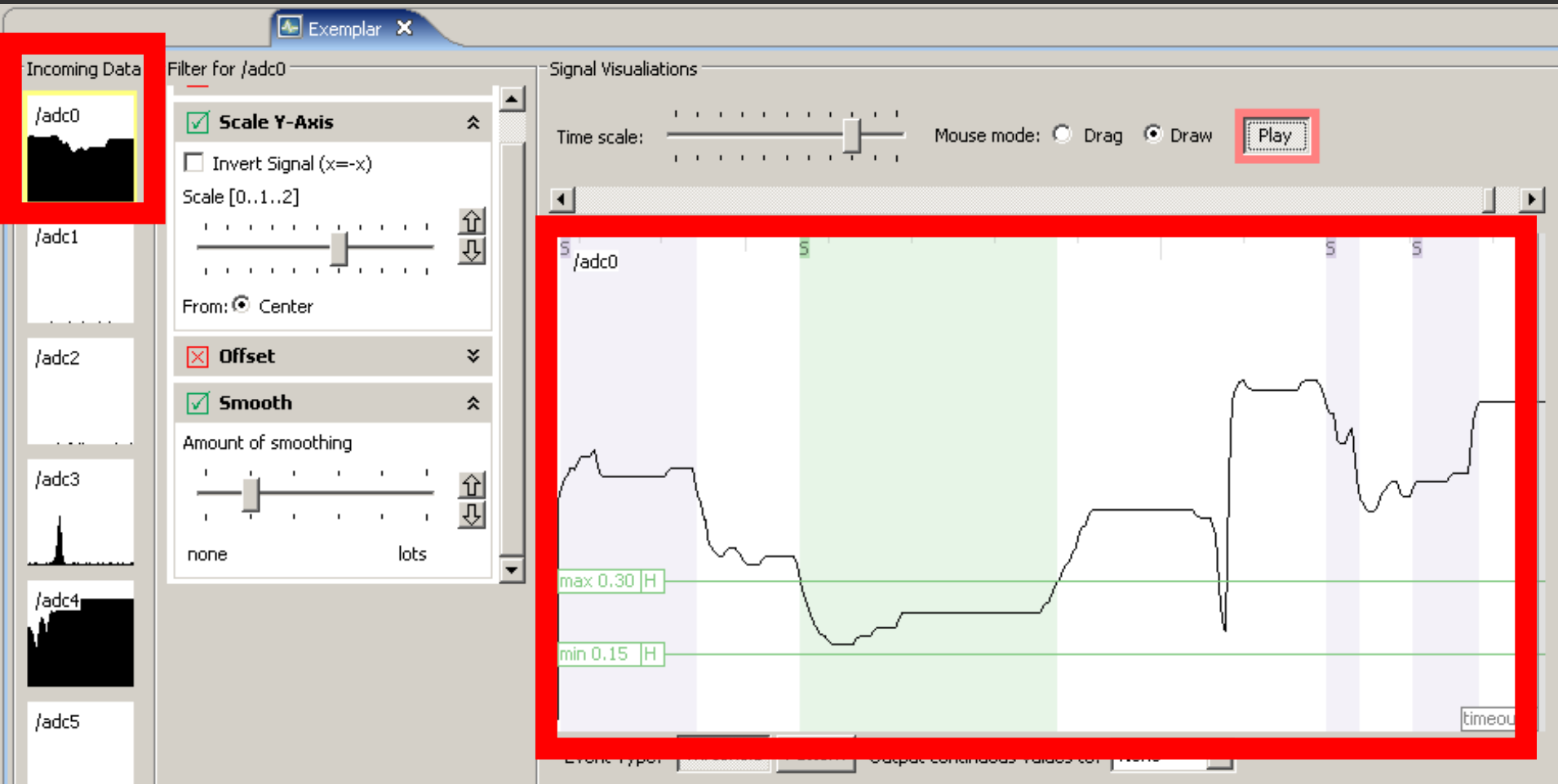
Filter for /adc0:

- Scale Y-Axis** (with expand/collapse arrows)
- Invert Signal ($x=-x$)**
- Scale [0..1..2] (with a slider and up/down arrows)
- From: Center
- Offset** (with collapse arrow)
- Smooth** (with expand/collapse arrows)
- Amount of smoothing (with a slider and up/down arrows)
- none (left) | lots (right)

Signal Visualizations:

- Time scale: (with a slider)
- Mouse mode: Drag Draw
- Play** button (highlighted with a red box)
- Plot area: Shows a signal waveform for /adc0. A green shaded region highlights a portion of the signal. Two horizontal green lines indicate 'max 0.30 |H' and 'min 0.15 |H'. A 'timeout' label is in the bottom right of the plot.
- Event Type:

Exemplar UI



Exemplar UI

The image shows a software interface for signal analysis. On the left, a list of incoming data channels is shown, with `/adc0` selected. A red box highlights the configuration panel for `/adc0`, which includes:

- Scale Y-Axis** (with an expand/collapse arrow)
- Invert Signal ($x=-x$)**
- Scale [0..1..2] with a slider and up/down arrows
- From: Center
- Offset** (with a collapse arrow)
- Smooth** (with an expand/collapse arrow)
- Amount of smoothing with a slider and up/down arrows, ranging from `none` to `lots`

On the right, the **Signal Visualizations** section contains:

- Time scale: a horizontal slider
- Mouse mode: Drag Draw
- Play** button (highlighted with a red box)
- A waveform plot for `/adc0` with a green shaded region. The plot shows a signal with a peak and a trough. Labels indicate `max 0.30 |H` and `min 0.15 |H`.
- Event Type: **Threshold** | **Pattern**
- Output continuous values to: **None** (dropdown menu)
- timeout

Exemplar UI

The image shows the Exemplar UI interface. On the left, the 'Incoming Data' section lists channels /adc0 through /adc5. Channel /adc0 is selected and highlighted with a yellow border. The 'Filter for /adc0' section contains several controls: 'Scale Y-Axis' is checked, 'Invert Signal (x=-x)' is unchecked, the 'Scale [0..1..2]' slider is set to approximately 1.5, and 'From: Center' is selected. Below this, 'Offset' is unchecked and 'Smooth' is checked. The 'Amount of smoothing' slider is set to approximately 1.5, with 'none' on the left and 'lots' on the right.

The 'Signal Visualizations' section on the right features a 'Time scale' slider, 'Mouse mode' options for 'Drag' and 'Draw' (with 'Draw' selected), and a 'Play' button highlighted with a red box. The main visualization area shows a waveform for /adc0 with a green shaded region. Two horizontal green lines indicate 'max 0.30 |H' and 'min 0.15 |H'. The 'Event Type' is set to 'Threshold', and the 'Output continuous values to:' dropdown menu is set to 'None' and highlighted with a red box. A 'timeout' label is visible in the bottom right corner of the plot area.

Exemplar UI

The image shows the Exemplar UI interface. On the left, the 'Incoming Data' panel lists sensors /adc0 through /adc7. The 'Filter for /adc0' panel includes settings for 'Scale Y-Axis' (checked), 'Invert Signal (x=-x)', 'Scale [0..1..2]', 'From: Center', 'Offset' (unchecked), and 'Smooth' (checked) with a smoothing amount slider. The 'Signal Visualizations' panel shows a 'Time scale' slider, 'Mouse mode' (Drag/Draw), and a 'Play' button. The main visualization area displays a signal for /adc0 with a green shaded region and horizontal lines for 'max 0.30 |H' and 'min 0.15 |H'. Below the plot are 'Event Type' (Threshold/Pattern) and 'Output continuous values to: None' options. On the right, the 'Events for /adc0' panel lists 'Event Bent' (Send as: /out1) and 'Event Extended' (Send as: /out3). The 'Overview of all events' panel shows a tree view of events for sensors /adc0, /adc3, and /adc4.

Scale Y-Axis
 Invert Signal (x=-x)
Scale [0..1..2]
From: Center
 Offset
 Smooth
Amount of smoothing: none to lots

Time scale: [Slider] Mouse mode: Drag Draw **Play**

Signal Visualizations: /adc0
max 0.30 |H
min 0.15 |H
Event Type: **Threshold** **Pattern** Output continuous values to: None

Events for /adc0
Name: Bent Send as: /out1
Name: Extended Send as: /out3

Overview of all events:
- Events for Sensor /adc0
 - Event Bent - outputs to: /out1
 - Marked Region
 - Event Extended - outputs to: /out3
- Events for Sensor /adc3
 - Event TiltLeft - outputs to: /key/left
 - Event TiltRight - outputs to: /key/right
- Events for Sensor /adc4
 - Event Foot Pedal - outputs to: /key/enter

Exemplar UI

The image shows the Exemplar UI interface. On the left, the 'Incoming Data' panel lists sensors /adc0 through /adc7. The 'Filter for /adc0' panel includes options for 'Scale Y-Axis' (checked), 'Invert Signal (x=-x)', 'Offset' (unchecked), and 'Smooth' (checked). The 'Signal Visualizations' panel shows a time scale, mouse mode (Draw selected), and a 'Play' button. The main plot displays a signal waveform with a green shaded region and horizontal lines for 'max 0.30 |H' and 'min 0.15 |H'. The 'Events for /adc0' panel shows two events: 'Bent' (Send as: /out1) and 'Extended' (Send as: /out3). A red box highlights an 'Overview of all events' panel, which lists events for sensors /adc0, /adc3, and /adc4 with their respective outputs.

Incoming Data

Filter for /adc0

- Scale Y-Axis
- Invert Signal (x=-x)
- Scale [0..1..2]
- From: Center
- Smooth
- Amount of smoothing: none to lots
- Offset

Signal Visualizations

Time scale: [Slider] Mouse mode: Drag Draw **Play**

Plot: /adc0, max 0.30 |H, min 0.15 |H, timeout

Event Type: Output continuous values to:

Events for /adc0

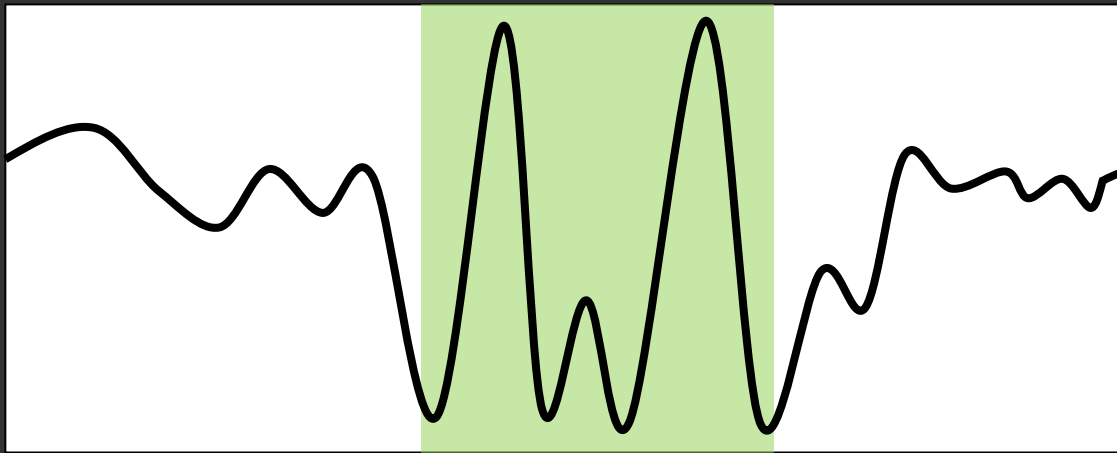
- Name: Bent Send as: /out1 [Remove] [Reset]
- Name: Extended Send as: /out3 [Remove] [Reset]

Overview of all events:

- Events for Sensor /adc0
 - Event Bent - outputs to: /out1
 - Marked Region
 - Event Extended - outputs to: /out3
- Events for Sensor /adc3
 - Event TiltLeft - outputs to: /key/left
 - Event TiltRight - outputs to: /key/right
- Events for Sensor /adc4
 - Event Foot Pedal - outputs to: /key/enter

[Flash animations from the talk are not included in this presentation.]

Dynamic Time Warping



Demonstration Signal

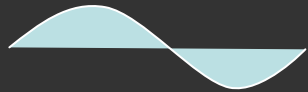
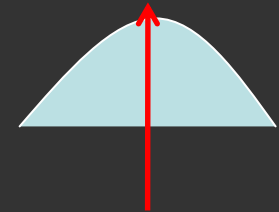


Matching Input Signal

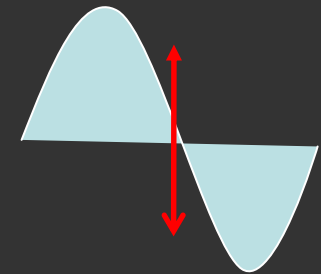
Filters



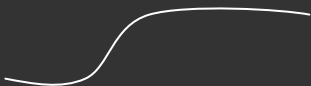
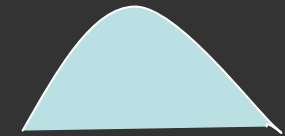
Offset



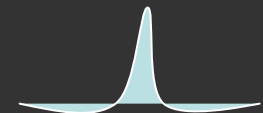
Y-Axis Scaling



Smoothing



Rate of Change



Extensible Filter Set

The image displays a software interface with two main windows. The top window, titled "MyCustomFilter.java", shows the following Java code:

```
public Float process(int time) {  
    int width=7;  
    return 0;  
}  
  
private Float median(int time, int width) {  
    List<Float> list= new ArrayList<Float>();  
    for(int i =0; i<width; i++) {  
        list.add(getInput(time-i));  
    }  
    Collections.sort(list);  
}
```

The bottom window, titled "Exemplar", is divided into three sections:

- Incoming Data:** A list of ADC channels from /adc0 to /adc5. /adc3 is selected and highlighted with a red background.
- Filter for /adc3:** A list of filters with checkboxes:
 - Rate of Change
 - Scale Y-Axis
 - Offset (with a slider for "Offset Value [-1..+1]")
 - Smooth
 - MyCustomFilter
- Signal Visualizations:** A plot for /adc3 showing a signal with several sharp peaks. The plot includes a "Time scale" slider, "Mouse mode" options (Drag and Draw), and a "Pause" button.
- Events for /adc3:** A table for event management:

Name:	Send as:	Remove
MyEvent	None	Reset

Buttons: Add, Overview of all events:

Understanding the Exemplar Approach

What?

Cognitive Dimensions of Notation (CDN) Inspection

First-Use Laboratory Study

Class Deployment

Used as Design Tools for
“Building Upon Everyday Play”
CHI Interactivity Exhibit

Why?

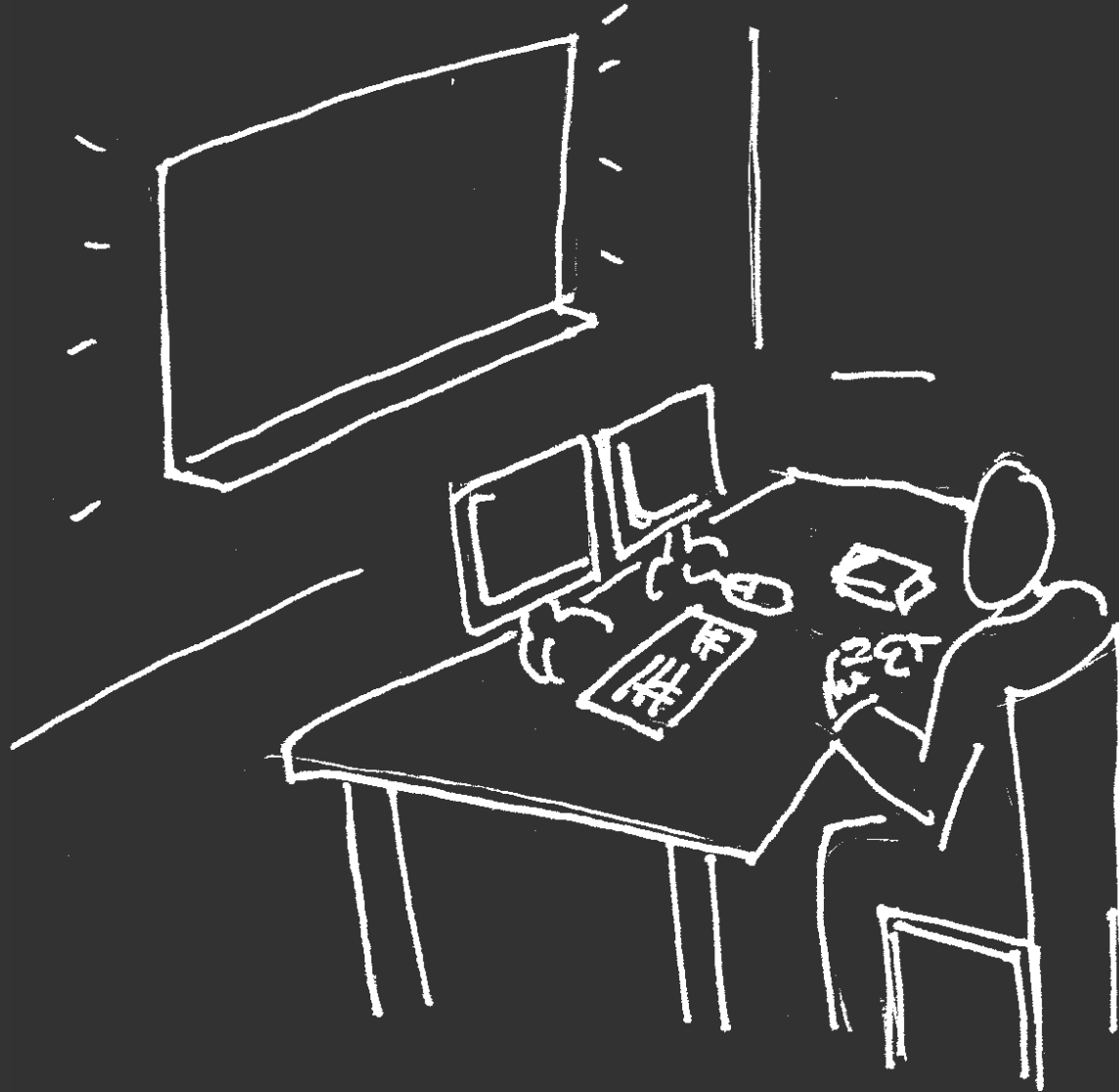
Analysis of Exemplar as a visual authoring environment

Threshold and usability

Real-world stress test

Complexity ceiling for knowledgeable users

Lab Study



[sketches by Wendy Ju]

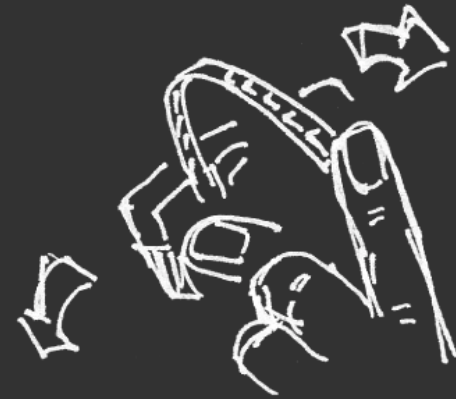
Lab Study



26 min



18 min



27 min



47 min



22 min

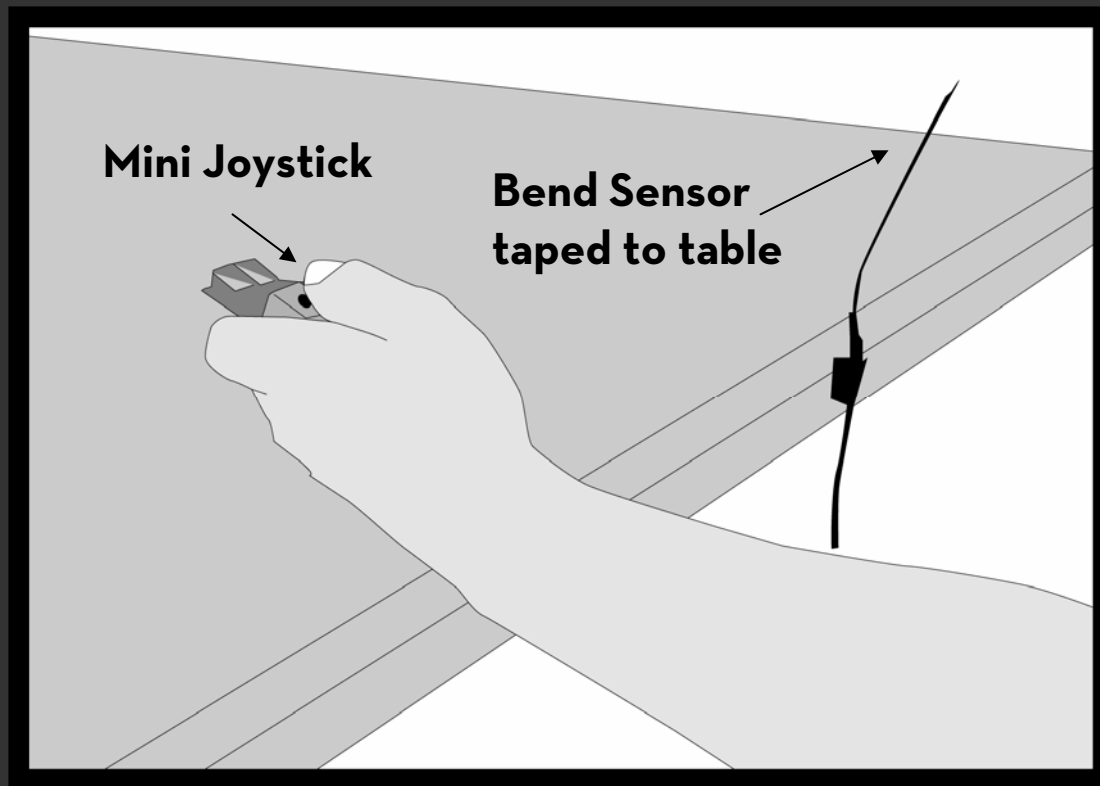


31 min

[sketches by Wendy Ju]

 Stanford iRoom





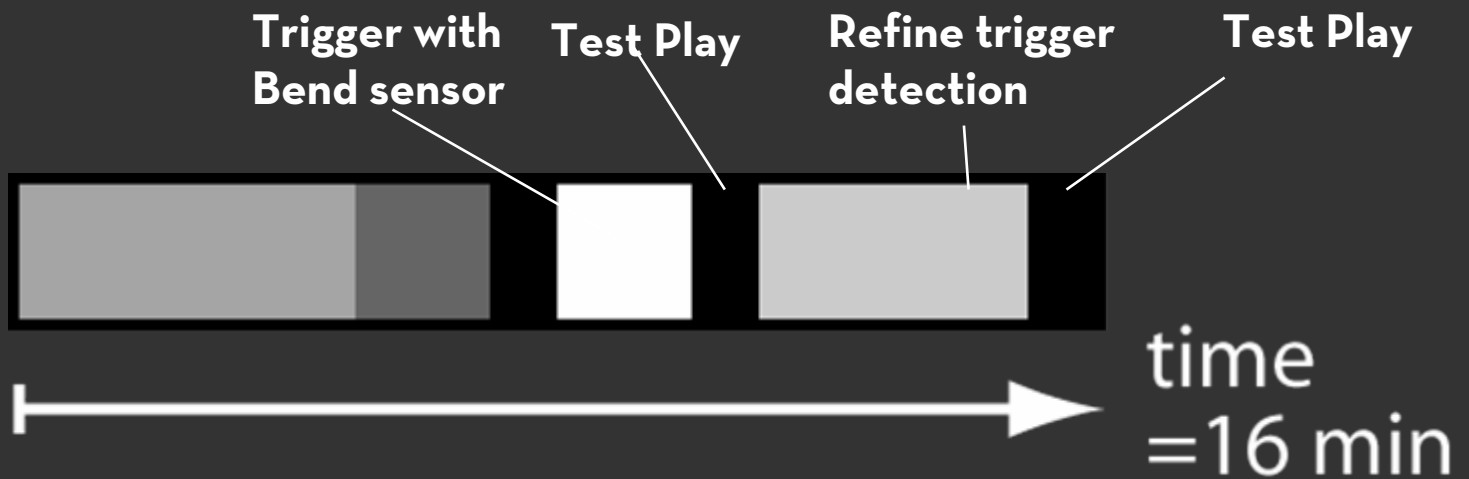
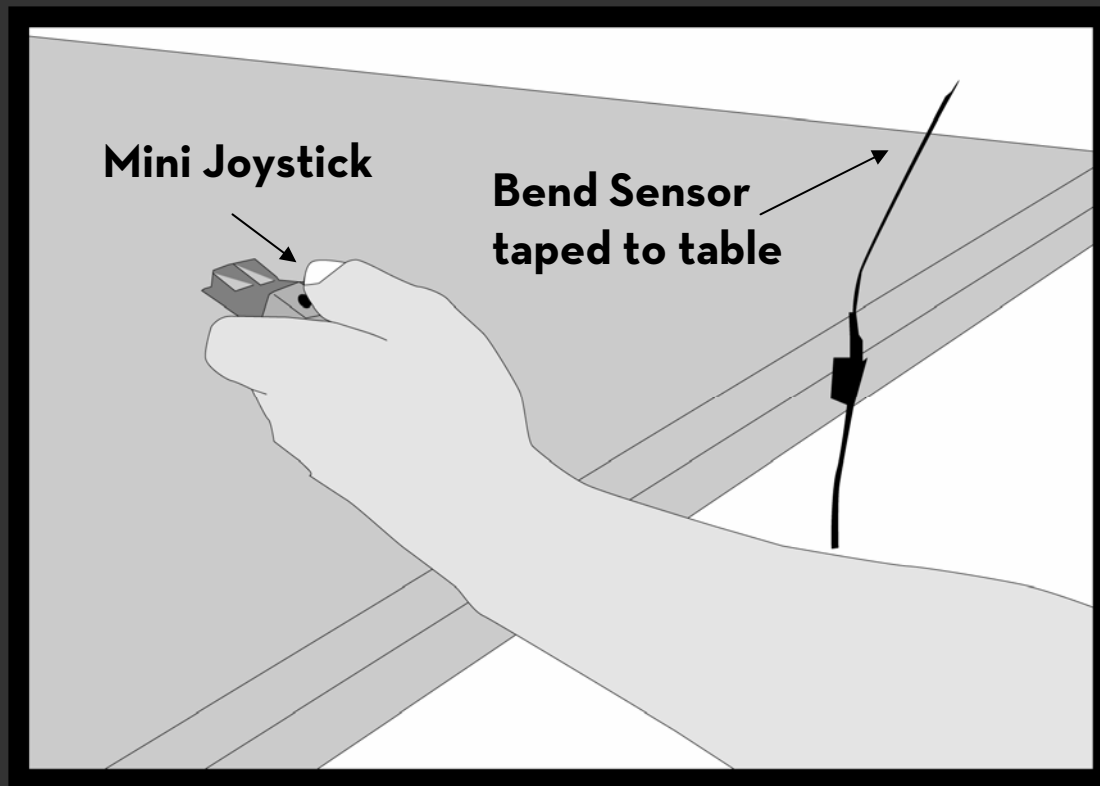
Navigation
with Accelerometer

Navigation
with XY Joystick

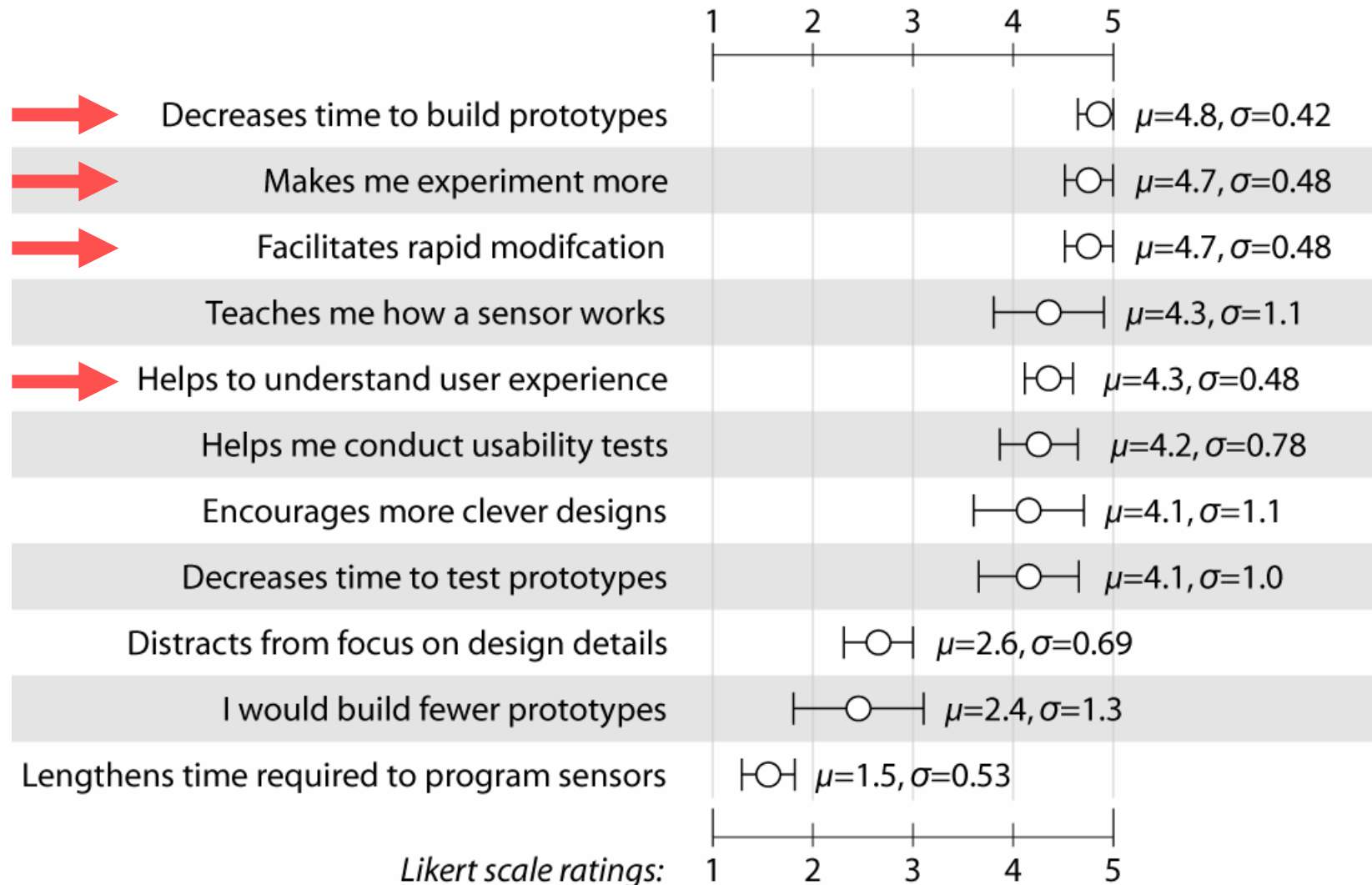
Test Play



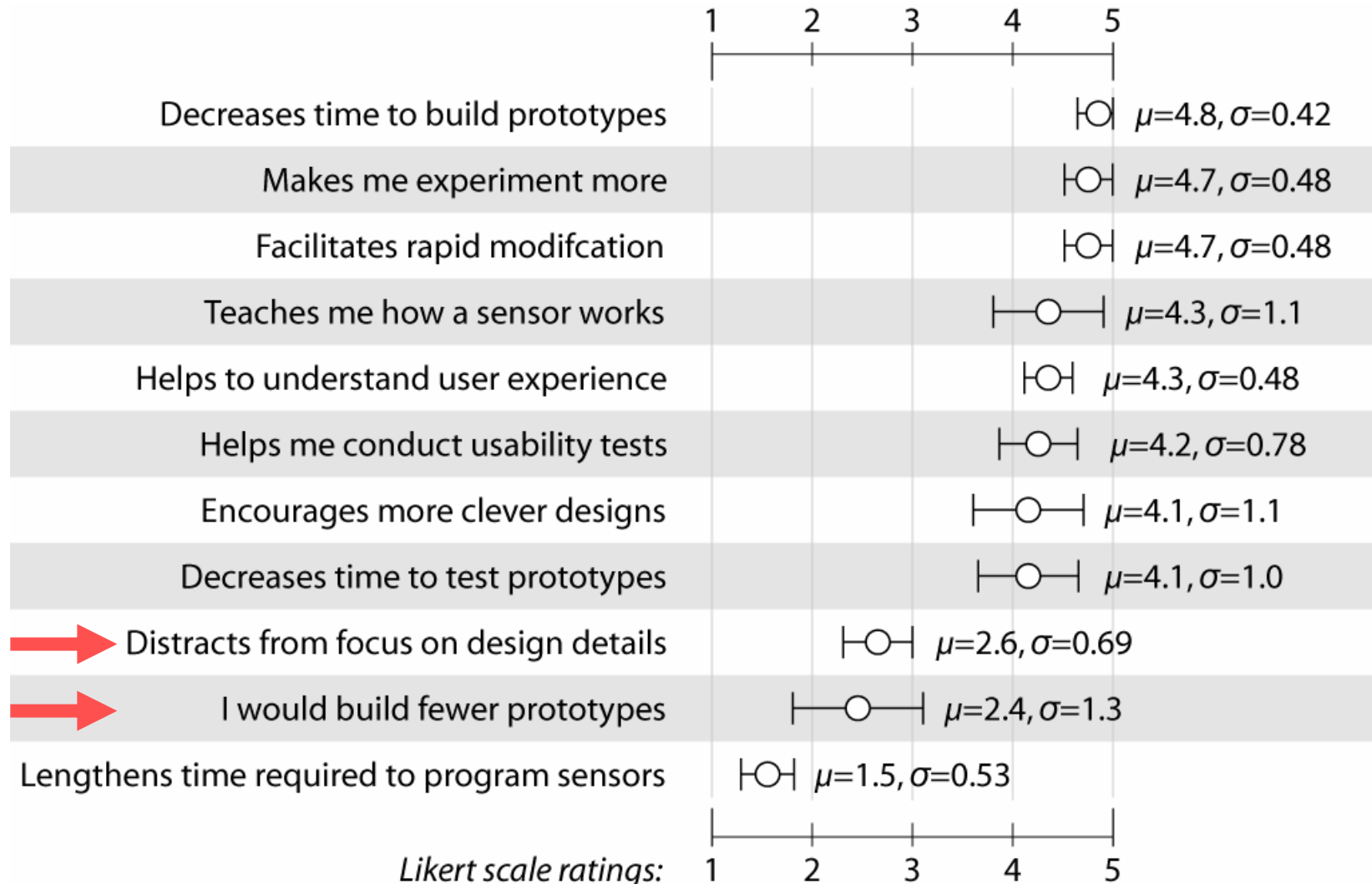
time
= 16 min



Post-Test Questionnaire



Post-Test Questionnaire



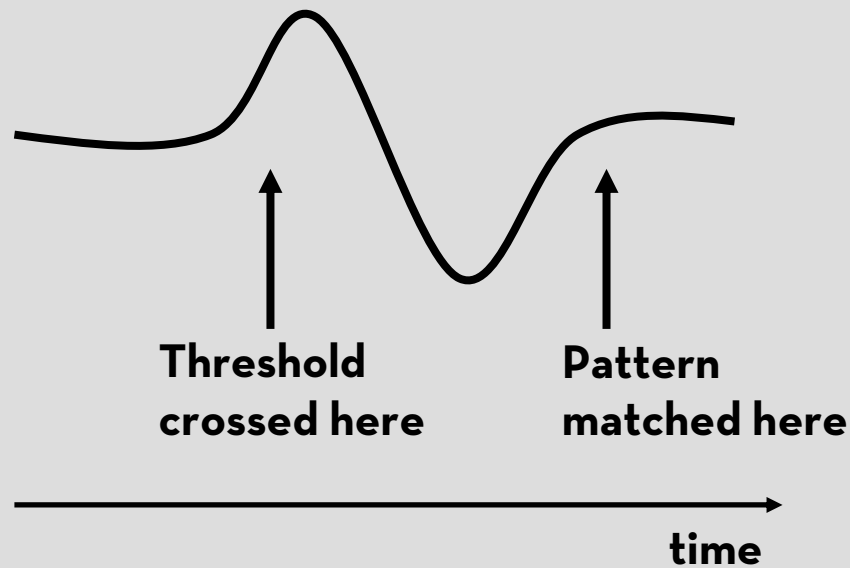
CHI Interactivity



[Control Freaks by Haiyan Zhang]

CHI Interactivity

Compulsory latency of pattern matching precludes use for fast-paced actions



Related Work

PBD TOOLS FOR UBIComp

a Capella
[Dey et al., CHI 04]

Crayons
[Fails & Olsen, CHI 03]

Monet
[Li, Landay, UIST 05]

Papier-Mâché
[Klemmer et al., CHI 04]

MUSICAL CONTROLLER DESIGN TOOLS

HID Toolkit
[Steiner, NIME 05]

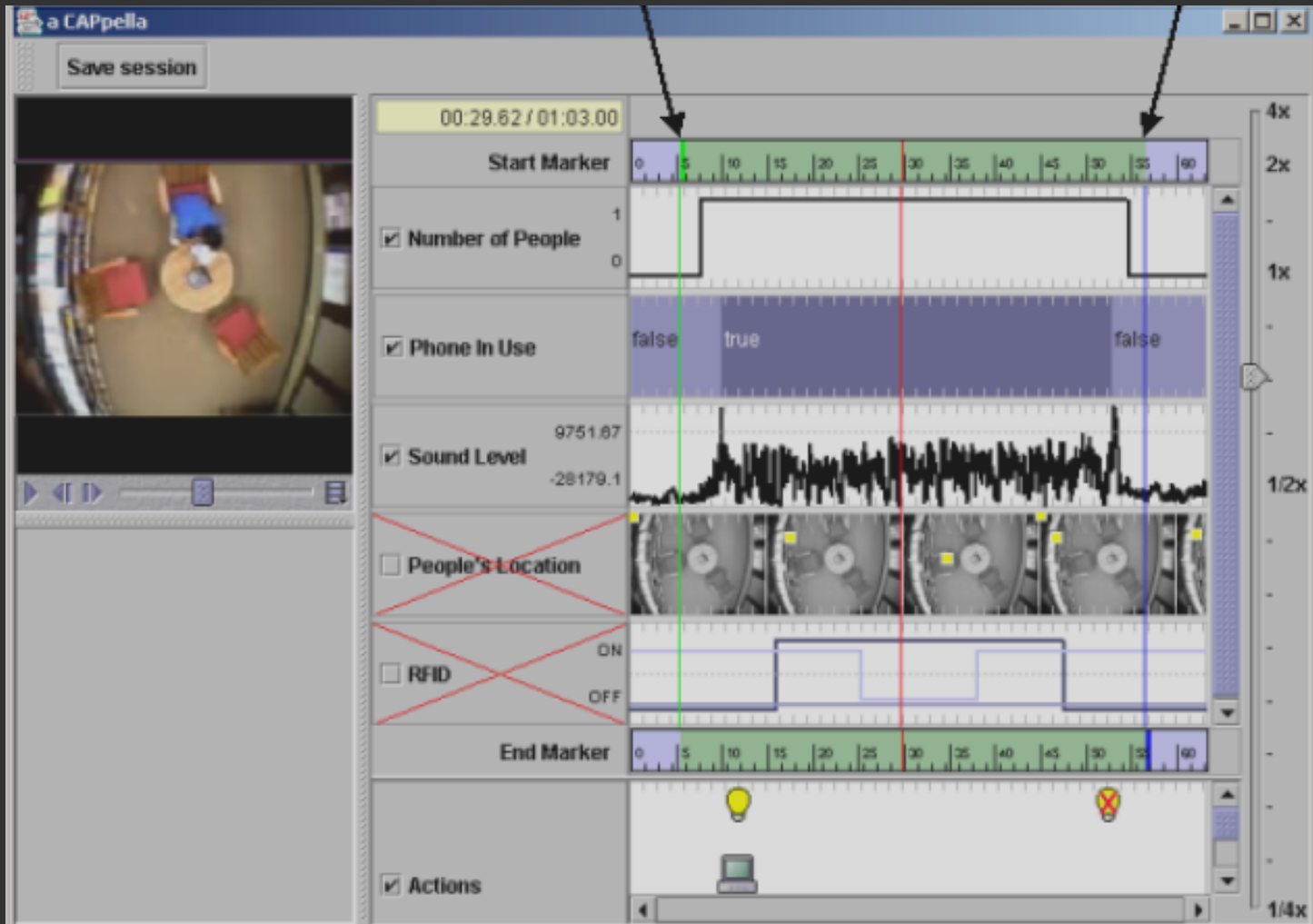
MnM
[Bevilacqua et al., NIME 05]

FlexiGesture
[Merrill & Paradiso, CHI 05]

COMMERCIAL DSP SOFTWARE

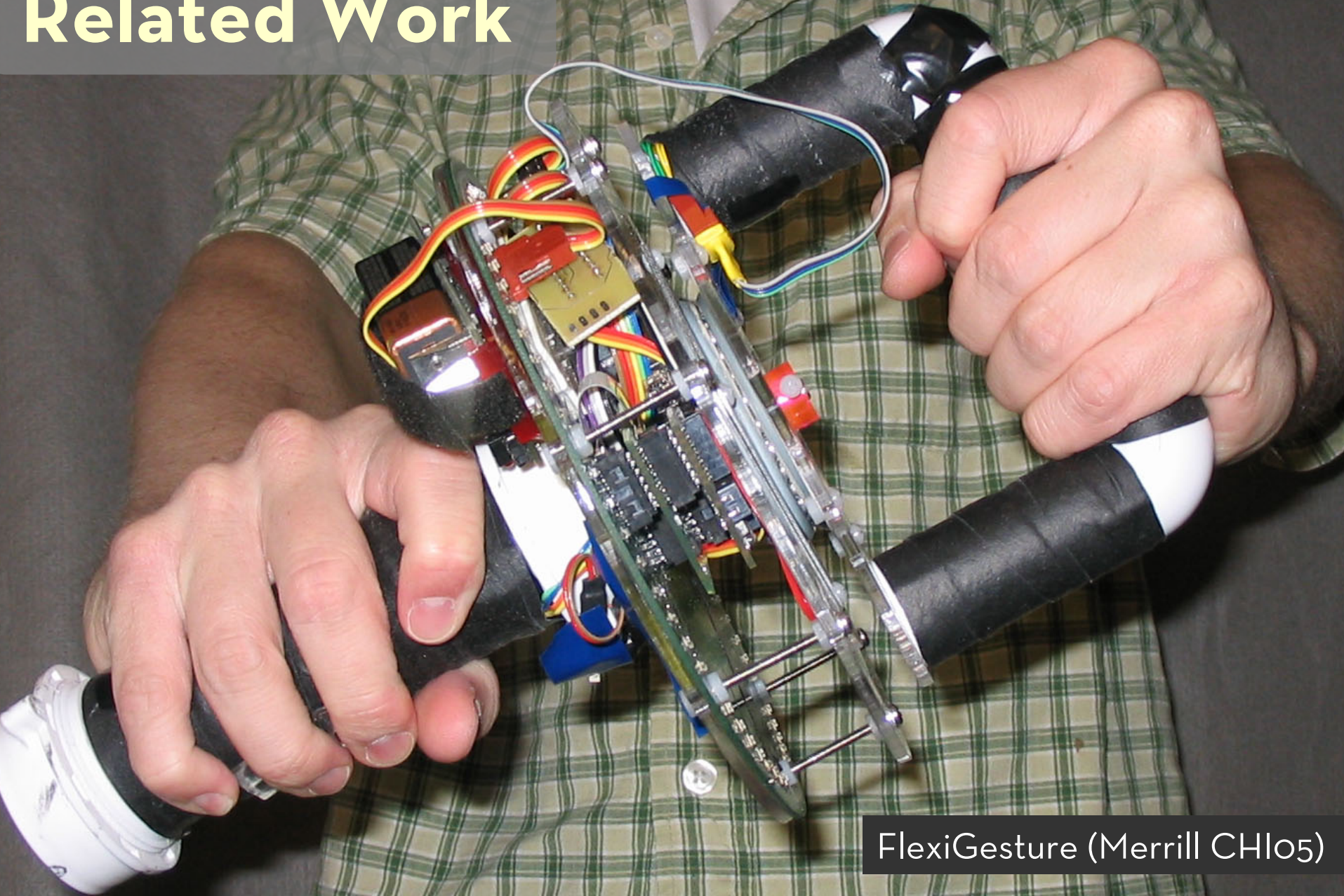
LabView/
Lego Mindstorms NXT

Related Work



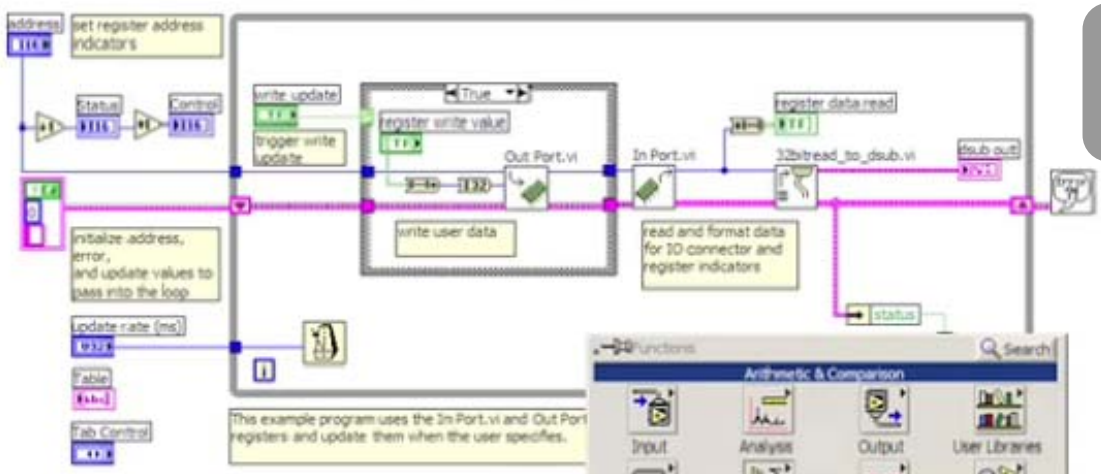
A CAPella (Dey et al., CHI 04)

Related Work



FlexiGesture (Merrill CH105)

Related Work



Functions palette showing categories: Arithmetic & Comparison, Input, Analysis, Output, User Libraries, Exec Ctrl, and Arith/Compert.

Express Numeric palette showing categories: Formula, Scale & Map, Time Domain, and Numeric.

Express Numeric Constants palette showing various mathematical operations and functions:

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- Increment, Decrement
- Absolute Value, Round, Round To -Inf, Round To +Inf
- Square Root, Negate, Scale By 2ⁿ, Sign, Reciprocal
- Compound Arith, Trigonometric, Logarithmic
- Constants

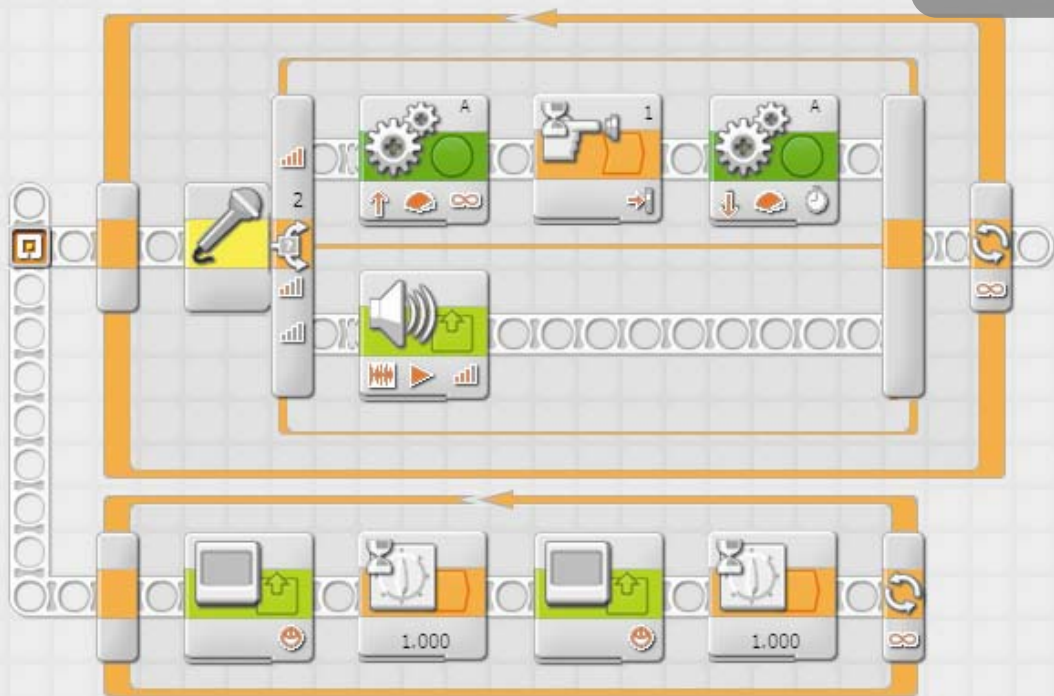
Express Numeric Constants palette showing physical constants:

- Pi, 2*Pi, Pi/2, 1/Pi, ln Pi, -Infinity
- e, 1/e, log e, ln 10, ln 2, +Infinity
- Planck Const, Elem Charge, c, G, Avogadro, Rydberg, Molar Gas Const

LabView

Related Work

Strike!



Move

Port: A B C

Direction: ↑ ↓ ← →

Steering: A B C

Power: 100

Duration: Seconds

Next Action: Brake Coast

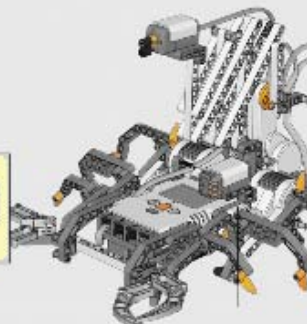
Lego Mindstorms NXT

Spike

3. Sound Sensor

Building Guide

Zoom



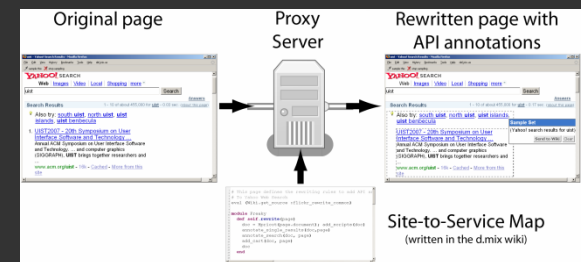
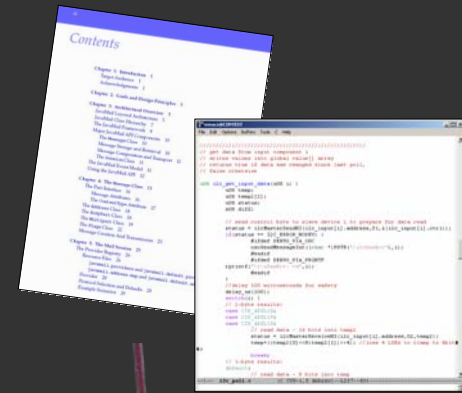
Future Directions

Export: Generate code + specifications

Programming sensor networks by demonstration

d.mix: Programming by A Sample for Web Service APIs

Integration of direct manipulation environments with textual programming



Acknowledgments

We thank **MediaX/DNP** for funding,
Intel for equipment donation,
Wendy Ju for illustrations,
David Merrill & Timo Arnall for photos.

Download Exemplar:
<http://hci.stanford.edu/exemplar>

CHI Interactivity “*Building Upon Everyday Play*”
Talk tomorrow, 11:30am, Room C2

