Advanced Human-Computer Interaction:
Tangible Interaction

Celine.Coutrix@imag.fr

Course objectives

- Answering basic questions, i.e.:
  - What are TUI?
  - What is their story?
  - What are they good for?
  - What are their limitations? + Research areas
- Building TUI

Tangible User Interfaces: What are they?

Tangible User Interfaces: What are they?

- Literally: Interfaces that involve physical objects that can be grasped
- Example: Durell Bishop Answering Machine http://vimeo.com/19930744

Tangible User Interfaces: What are they?

- Graphical User Interfaces
  - interfaces usually limited to std screen+keyboard+mouse
- Virtual Reality Interfaces
  - interfaces to immerse the user in a digitally generated world
- Augmented Reality (AR) and Augmented Virtuality (AV)
  - Tangible Interfaces belong to AR+AV
- Haptic Interaction
  - Tangible Interfaces belong to Haptic: Both involve touch and manipulation, but haptic usually not passive

Spread

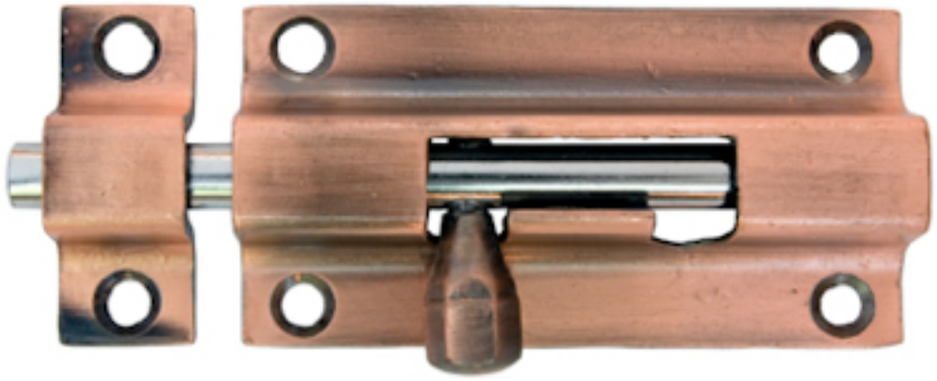
- **Interaction paradigms**
  - GUI & Tangible: SLAP Widgets
    - https://www.youtube.com/watch?v=I2rDHUUkd5Y
  - RA & Tangible : InSide
    - https://vimeo.com/100085425
- **Tasks**
  - Visu & Tangible:
    - http://research.microsoft.com/en-us/um/cambridge/projects/physicalcharts/
  - Remote collaboration & Tangible:
    - https://vimeo.com/108402837

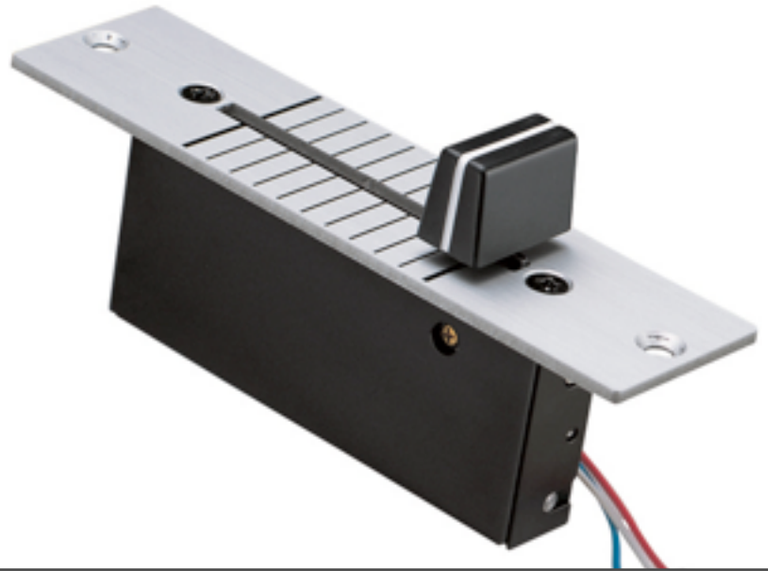
Tangible User Interfaces

- What is their story?

Tangible User Interfaces

- Manipulation of tangible tools has always been there...





Tangible User Interfaces

- ... and is still there

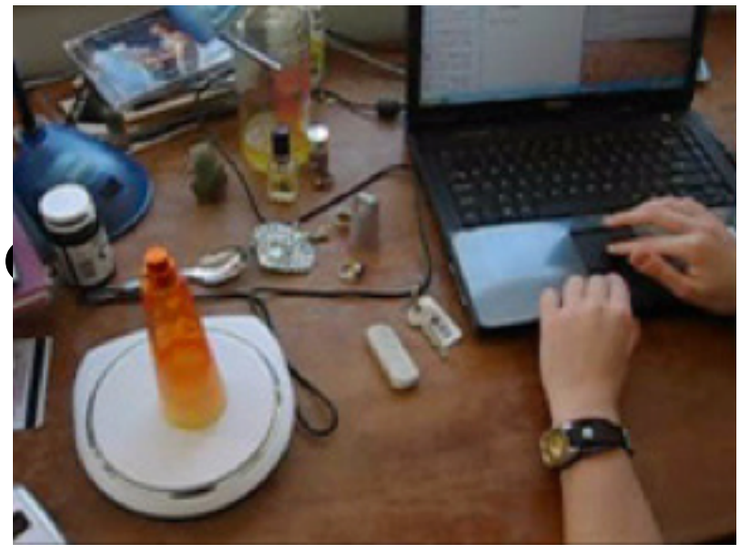
Tangible User Interfaces

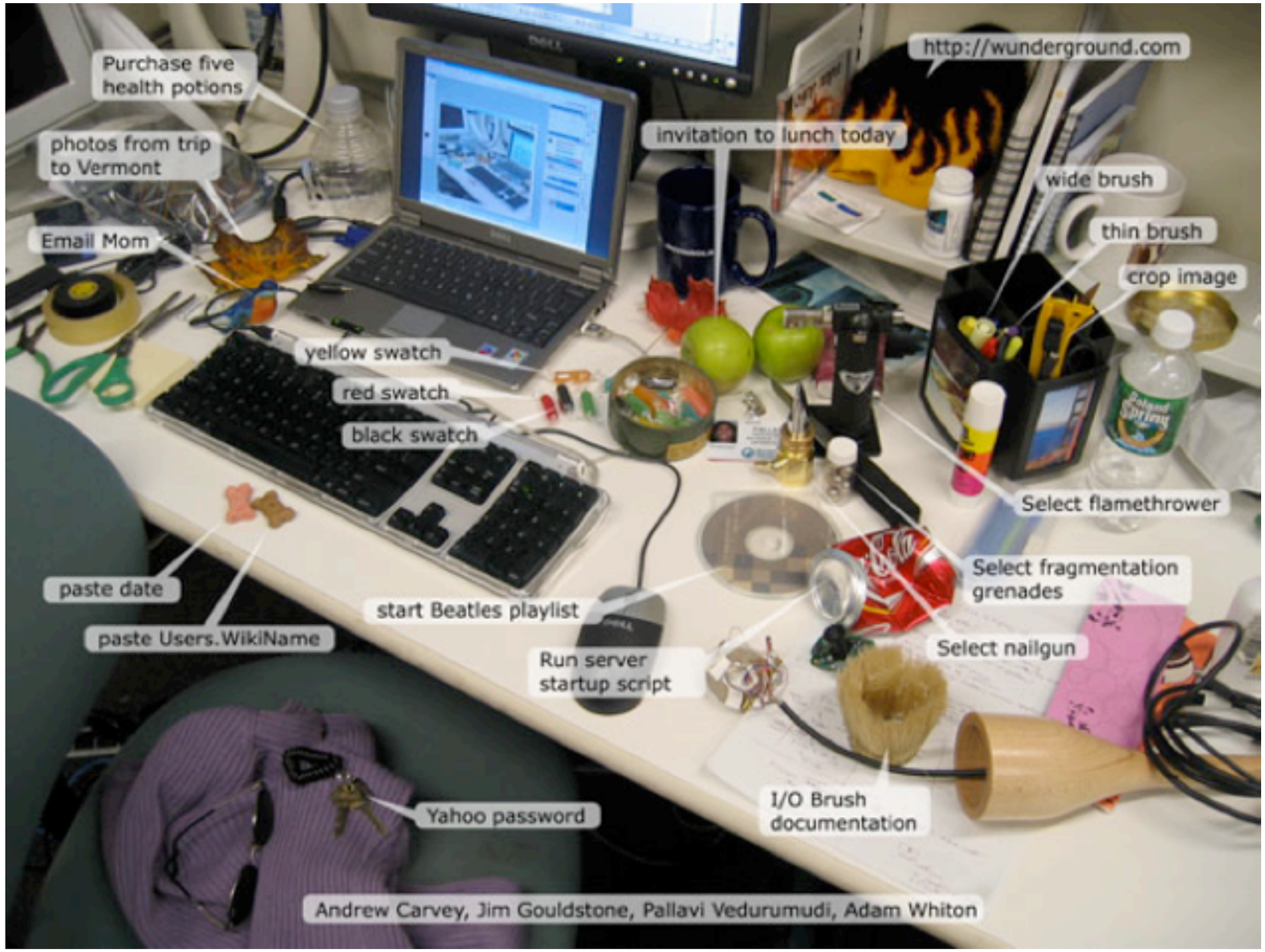
- Seminal papers
  - Foundations of Graspable User Interfaces: Bricks
  - Digital Desk

Tangible User Interfaces

- Early works
  - DataTiles: Tangible overlay mixing Tangible and Graphical Interaction
    - https://www.youtube.com/watch?v=cmD8EKWxD4M
  - Containers: mediaBlocks
    - http://vimeo.com/48827402
  - metaDesk:
    - http://vimeo.com/44545109
  - 3D animation with tangible sliders (1996):
    - https://www.youtube.com/watch?v=SnDHjY5aD5c

Tangible User Interfaces





http://dl.acm.org/citation.cfm?doid=1125451.1125582

Tangible User Interfaces

- ReacTable (2006)
  - https://www.youtube.com/watch?v=0h-RhyopUmc
  - https://www.youtube.com/watch?v=MPG-LYoW27E

Tangible User Interfaces

- I/O Brush

Tangible User Interfaces

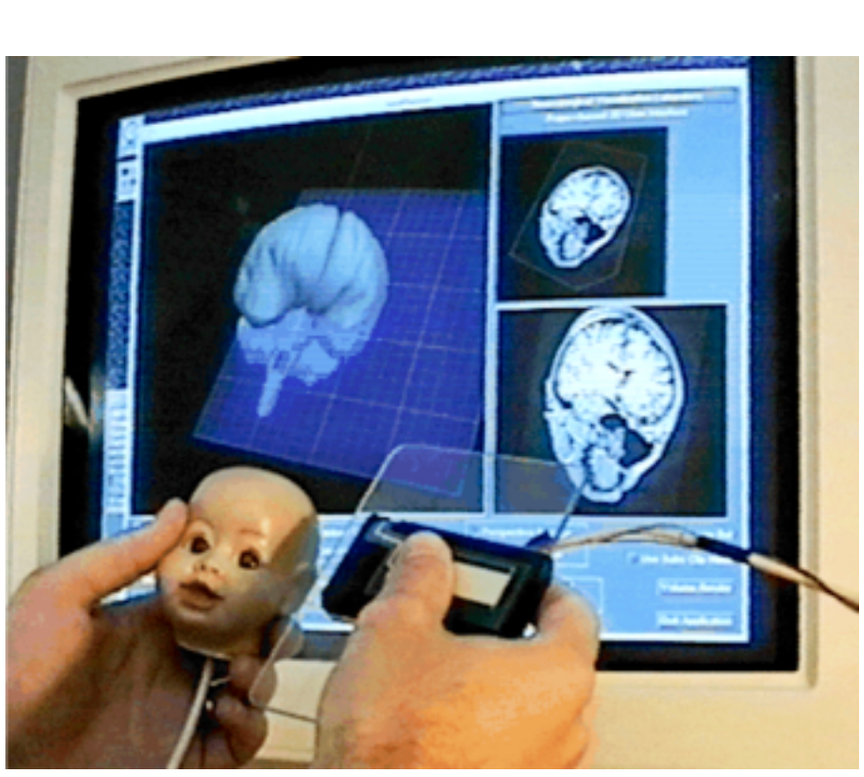
- What are they good for?

Tangible User Interfaces

- What are they good for?
  - Interaction embodied in the physical world of the user: *Physical* User & *Physical* Interface
  - Performance: passive haptic feedback

Embodiment

- Embodied interaction
  - Object (prop) to interact at a distance with GUI



17

Embodiment

- Embodied interaction
  - Tangible and overlaid projection, e.g. URP
    - https://vimeo.com/48600713

Embodiment

- Embodied interaction
  - Rear-projection and optical fibers
- https://www.youtube.com/watch?v=82r4l9Ks5Zc

Embodiment

- Embodied interaction
  - Printed Optics
- https://www.youtube.com/watch?v=eTeXTbXA6-Y

Fishkin's metaphors

- Metaphor = Analogy between the system effect of a user action to the real-world effect of similar actions
  - None = No analogy between action and result
    - E.g., command-line UI, clock in URP
  - Noun = shape-related: "an <X> in the system is like an <X> in the real world"
    - E.g., dictionary (http://dl.acm.org/citation.cfm?doid=302979.303111)

  - Verb = motion-related: "<X>-ing in our system is like <X>-ing in the real world"
    - E.g., NAVRNA

  - Noun & Verb = "<X>-ing an <A> in our system is like <X>-ing something <A>-ish in the real world"
    - E.g., eraser in Digital Desk, building in URP
  - Full = In user's mind, there is no system
    - E.g., Illuminating Clay (http://vimeo.com/44537533)

Tangible User Interfaces

- What are they good for?
  - Several experiments demonstrated their benefits

Tangible User Interfaces

- Time-multiplexed vs. Space-multiplexed input: inter-device transaction phases
- Specialized vs. Generic form-factor

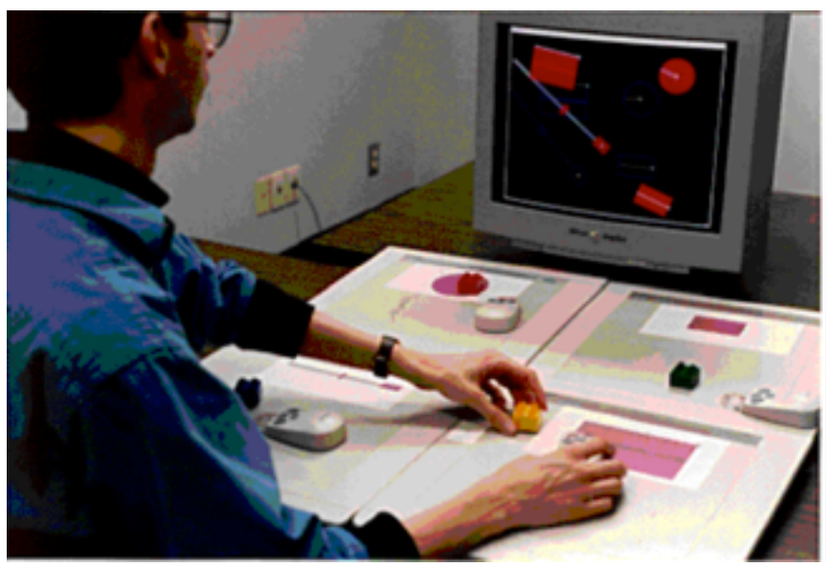
Tangible User Interfaces

- Time-multiplexed vs. Space-multiplexed input: inter-device transaction phases

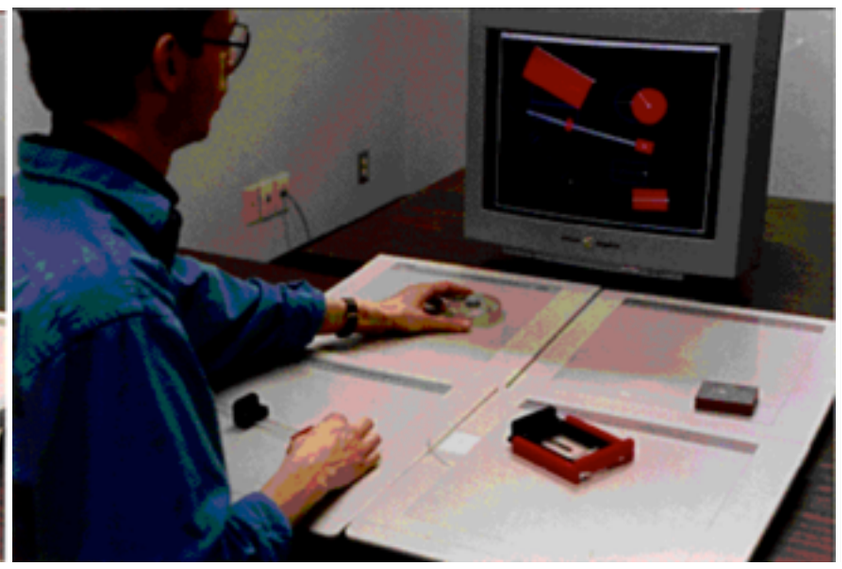
GUI	TUI
Acquire physical device ↓ Acquire logical device ↓ Manipulate logical device	Acquire physical device ↓ Manipulate logical device

Tangible User Interfaces

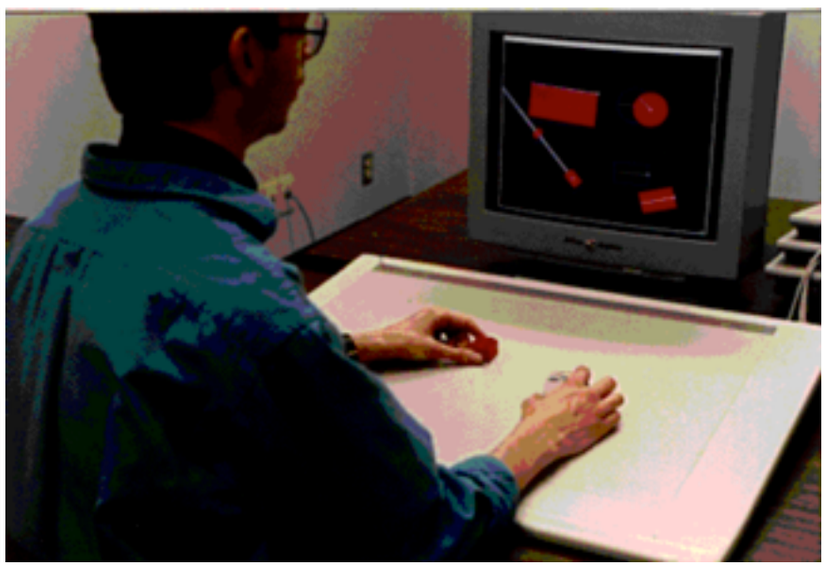
- Task: continuously *track* four targets moving randomly on the screen
  - Tracking are compound tasks:
    - Rotor: position and rotation
    - Brick: position and rotation
    - Strechable square: position, rotation and scale
    - Ruler: position, rotation and scale



Specialized, Space-multiplexed



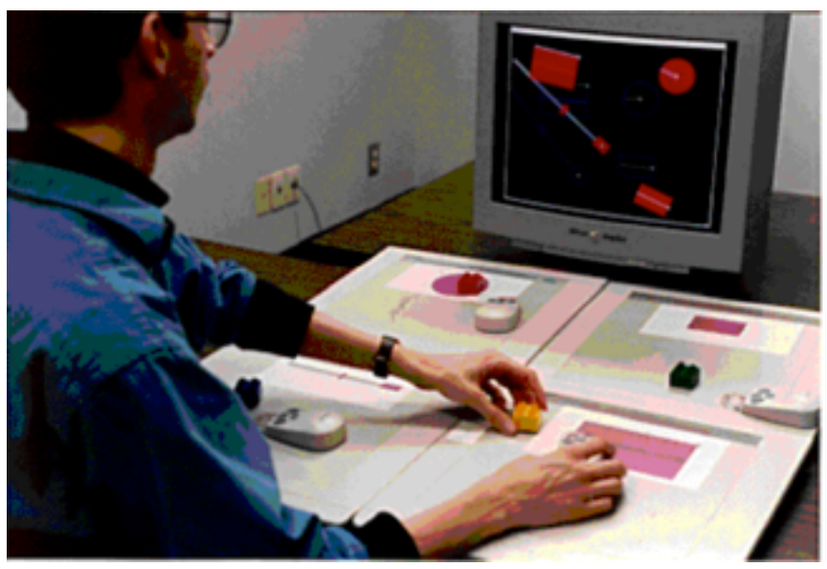
Generic, Space-multiplexed



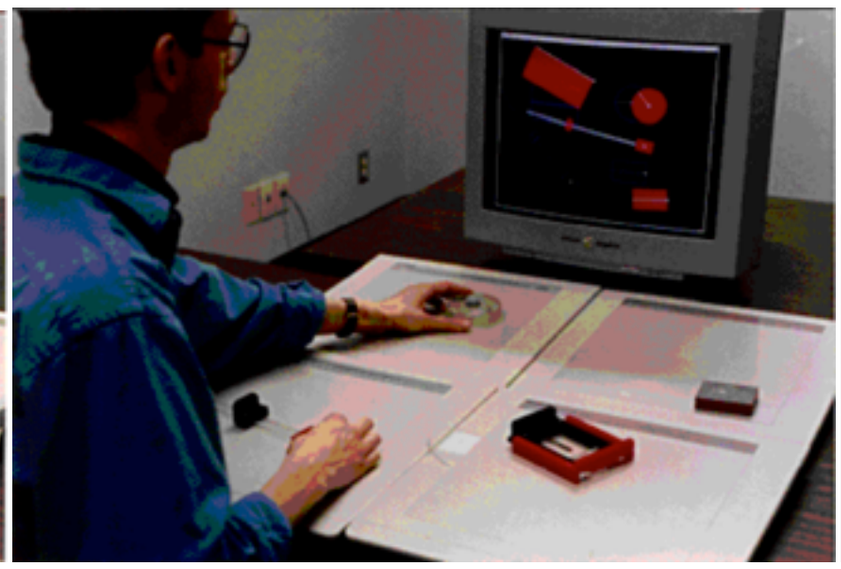
Time-multiplexed

Tangible User Interfaces

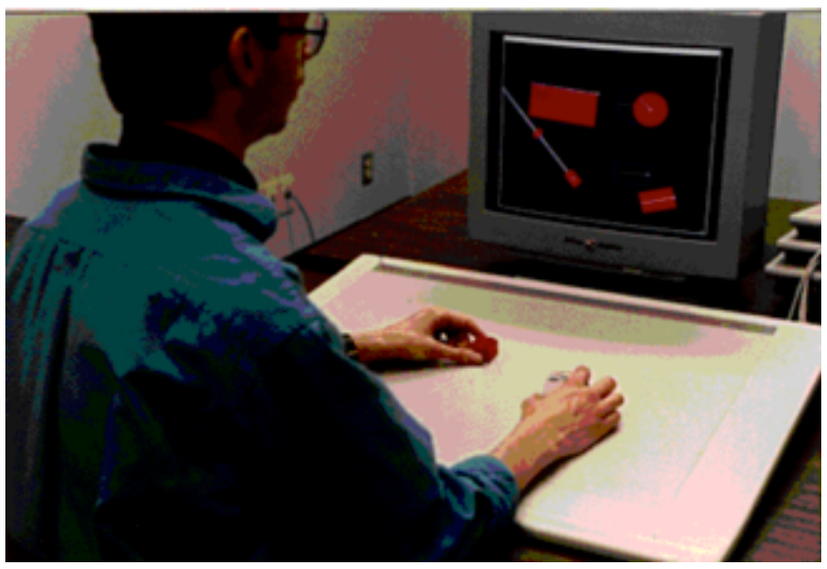
- Does the physical switching cost more than the logical switching between tools?



Specialized, Space-multiplexed



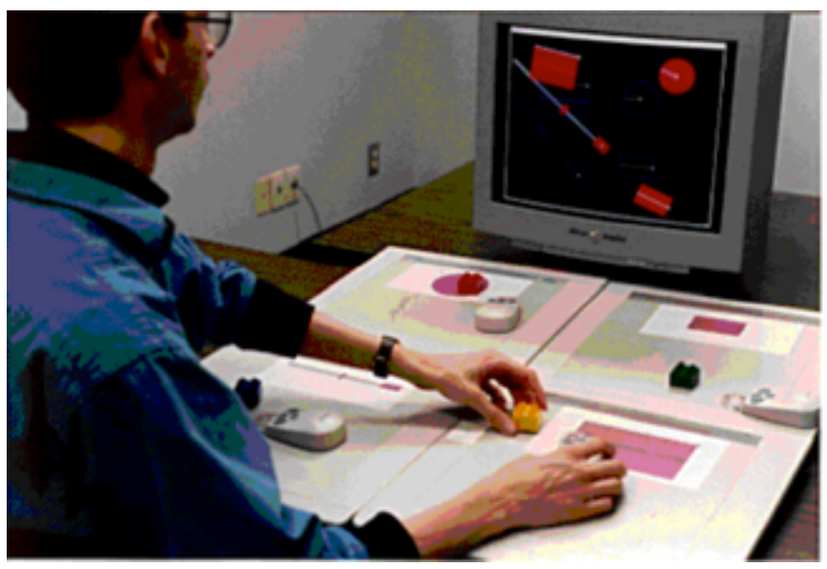
Generic, Space-multiplexed



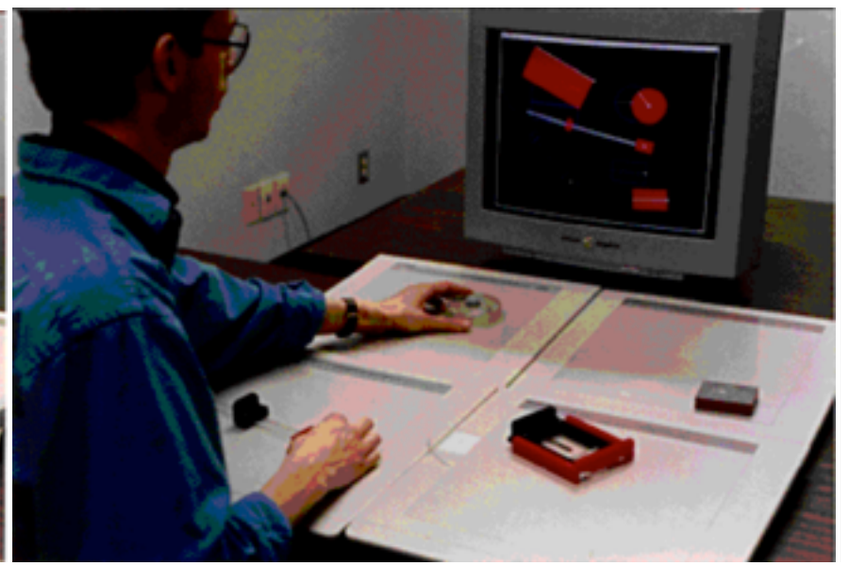
Time-multiplexed

Tangible User Interfaces

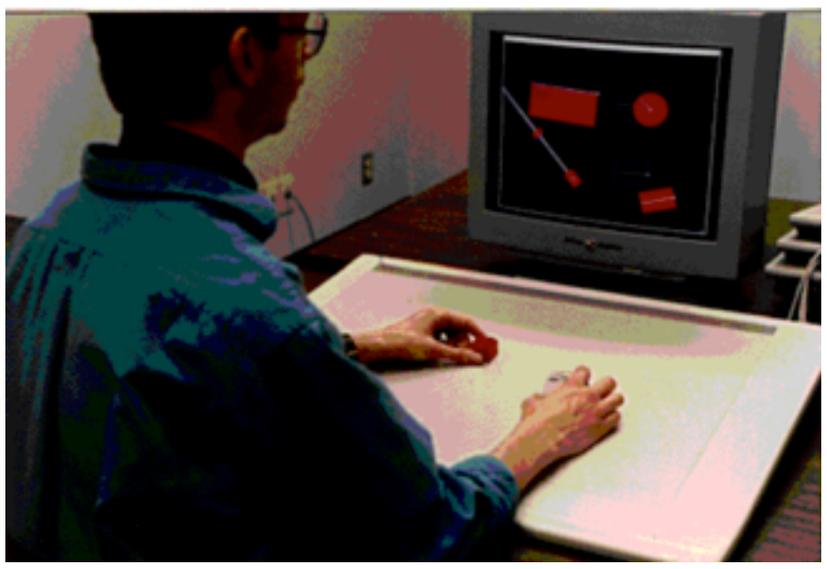
- Does the physical switching cost more than the logical switching between tools?
- Is the specialized input useful?



Specialized, Space-multiplexed

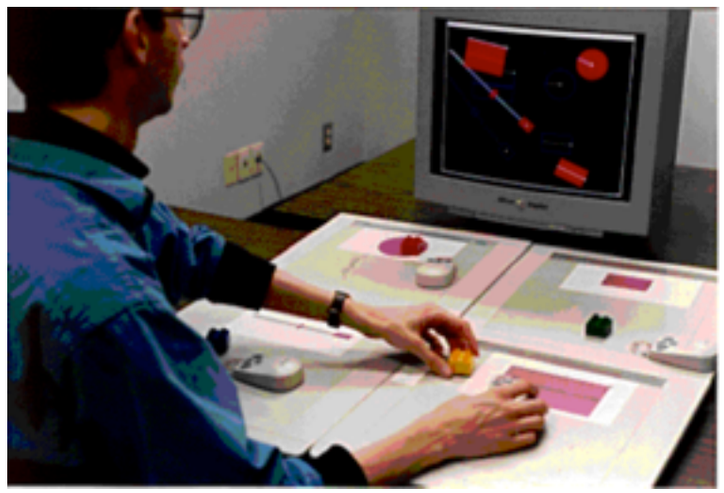


Generic, Space-multiplexed



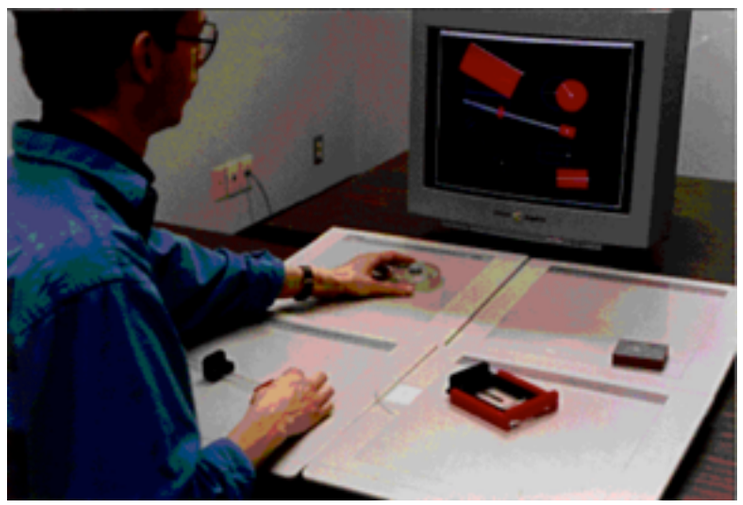
Time-multiplexed

Tangible User Interfaces



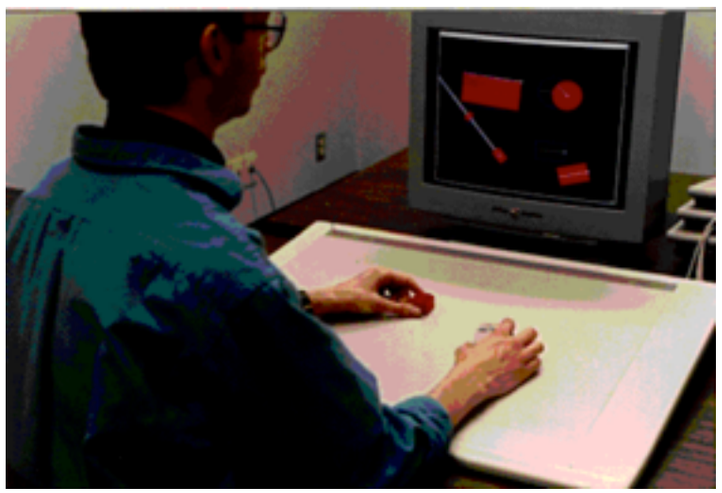
Specialized, Space-multiplexed
performs best

>



Generic, Space-multiplexed
performs better than Time-multiplexed
but worst than Specialized

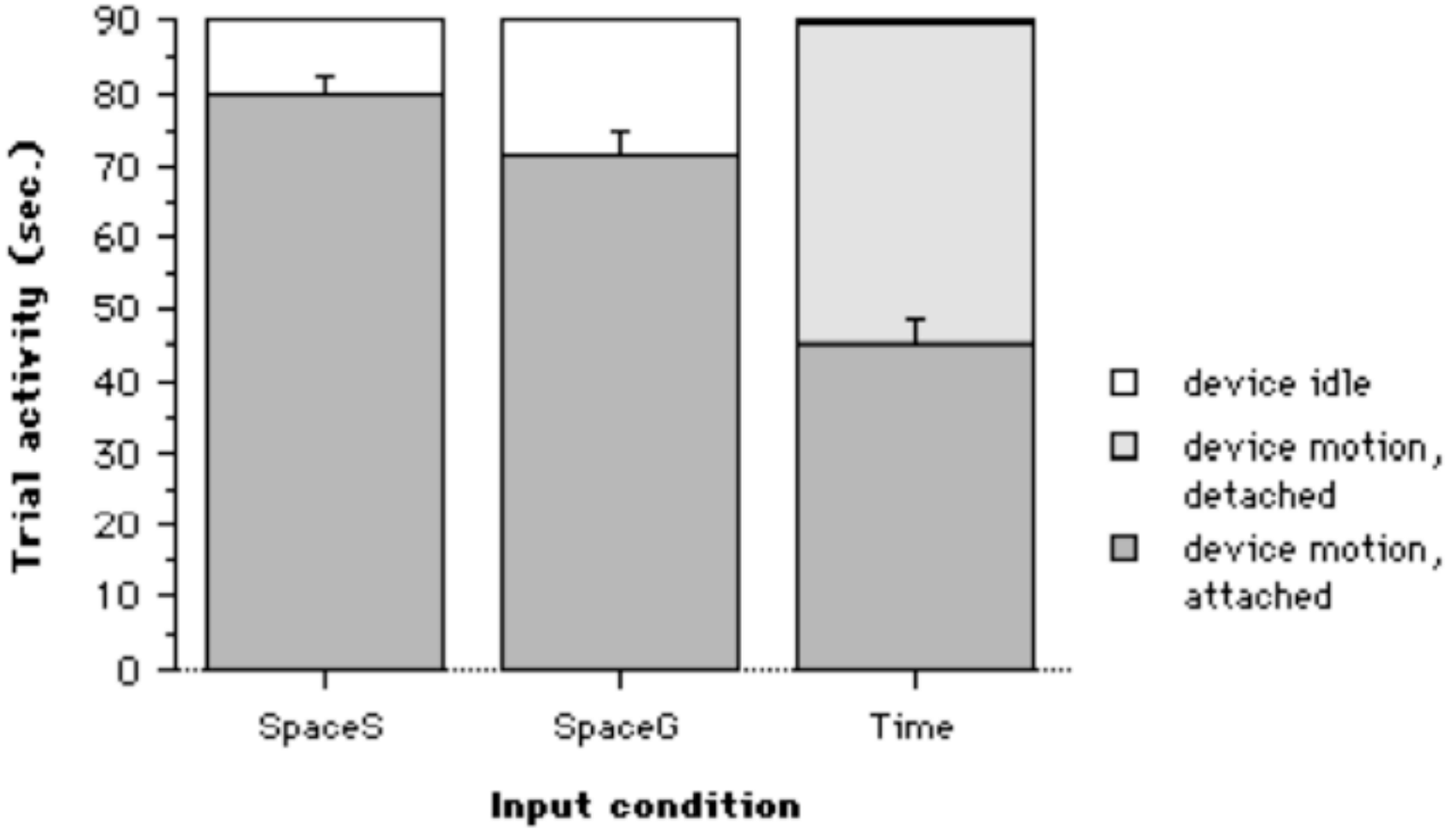
>



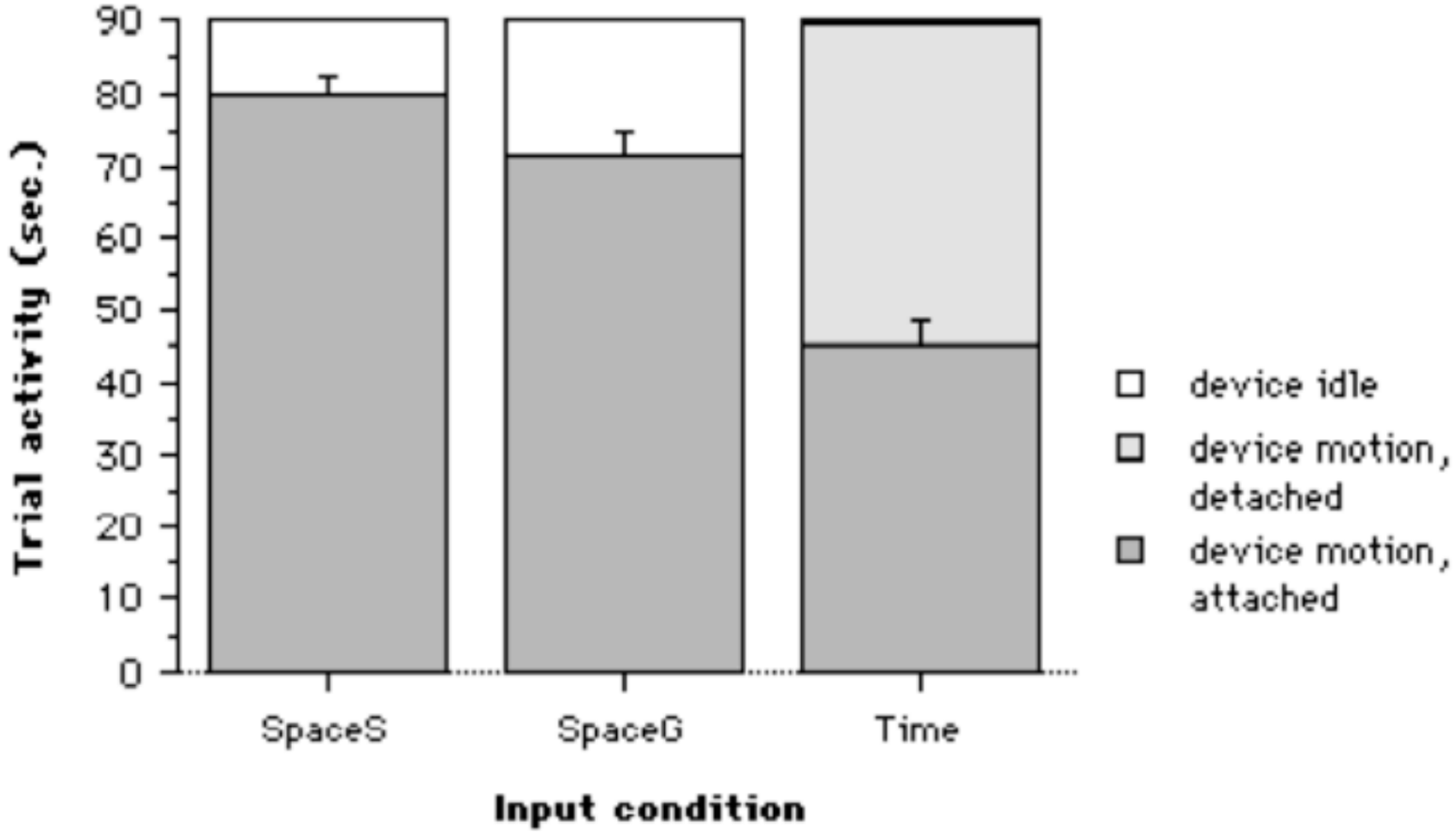
Time-multiplexed
performs worst

- Consistent across the 4 devices
- (Score based on root mean square errors of all dimensions (position, orientation and scale if applicable) of all devices)

Tangible User Interfaces



Tangible User Interfaces



- Users spend more time switching between tools with time-multiplexed UI rather than with space-multiplexed UI

Tangible User Interfaces

- Space-multiplexed > Time-multiplexed input:
  - Persistance of attachement between physical and logical (software, graphical) controllers
  - Parallel 2-handed vs. Sequential 1-handed interaction
- Specialized vs. Generic form-factor
  - Visual and tactile reminder

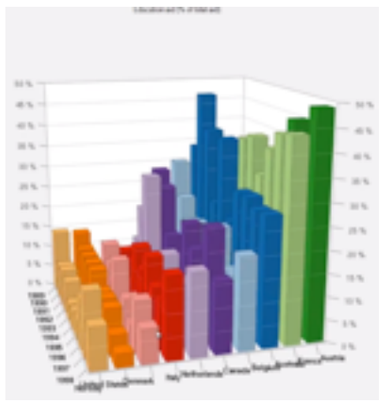
Tangible User Interfaces

- What are they good for?
  - Several experiments demonstrated their benefits

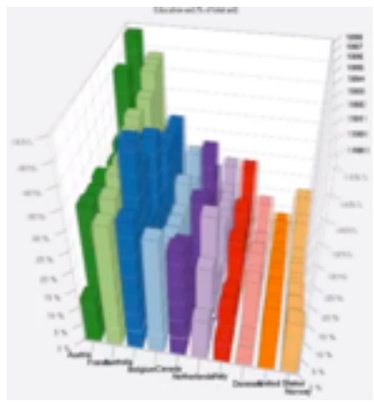
Tangibles User Interfaces

2D

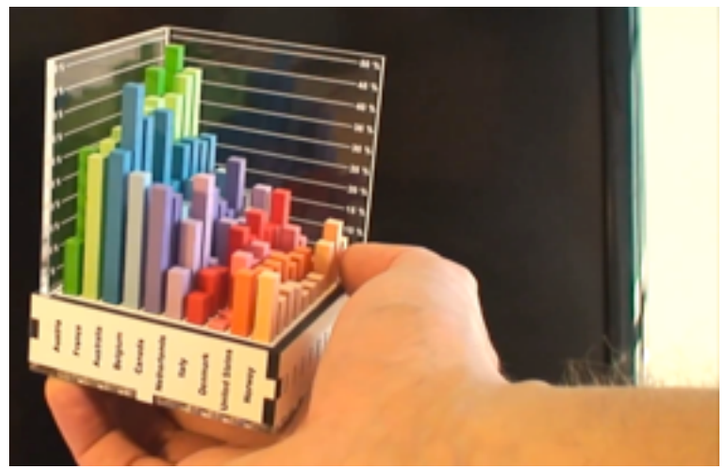
3D Mono



3D Stereo



Tangible



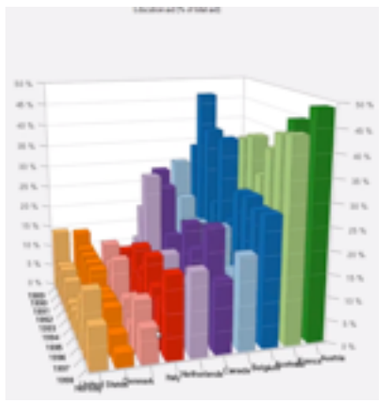
- Tasks
  - Find and indicate a range of values
  - Find and sort values
  - Find and compare values

- Measures
  - Time
  - Error rate

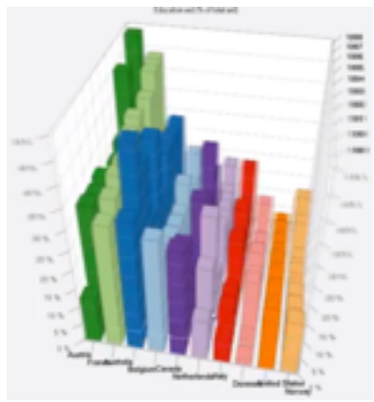
Tangibles User Interfaces

2D

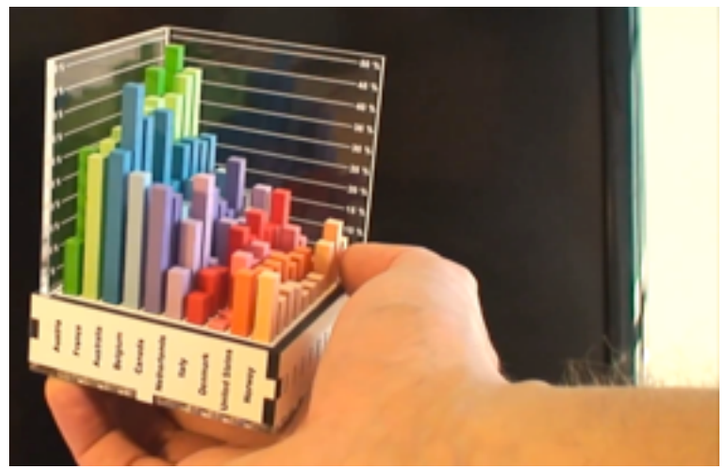
3D Mono



3D Stereo



Tangible

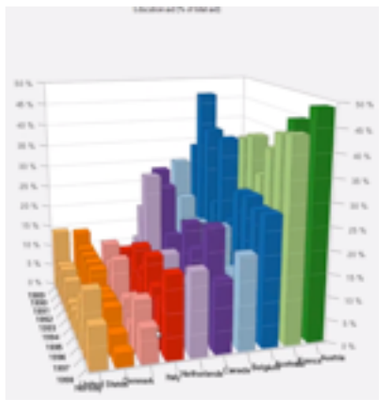


- Users are:
  - Around 20% faster with Tangible than with 3D
  - Around 40% faster with 2D than with Tangible
    - however, effect weaker if the task cannot be solved by one 2D cut

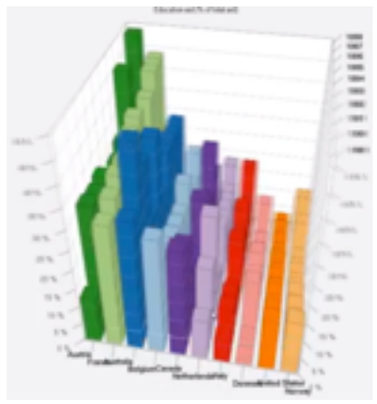
Tangibles User Interfaces

2D

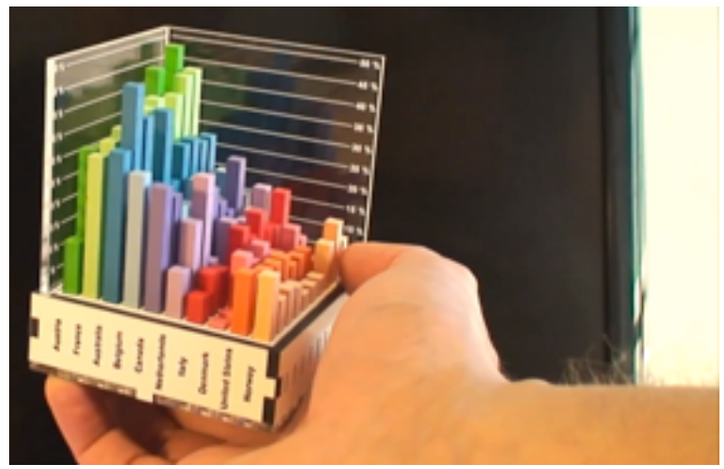
3D Mono



3D Stereo



Tangible



- Among possible explanation: Touch & Proprioception

3D mono/stereo	**Tangible**
sequential: rotate; mark; rotate; etc.	parallel: rotate // mark*
occluded bars impossible to reach with the mouse cursor	occluded bars reachable with the fingers
mouse cursor does not occlude the bars	proprioception compensate for fingers that occlude the bars

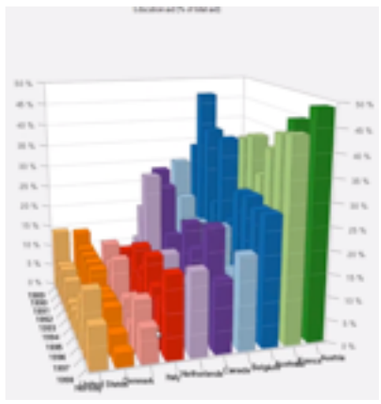
Proprioception

- Definition:
  - Perception of our own body
  - Sense of the relative position of our limbs through our skin, muscle, joints and inner ear

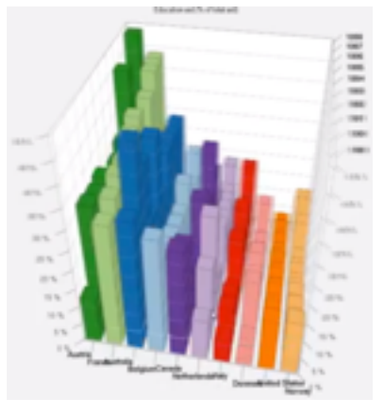
Tangibles User Interfaces

2D

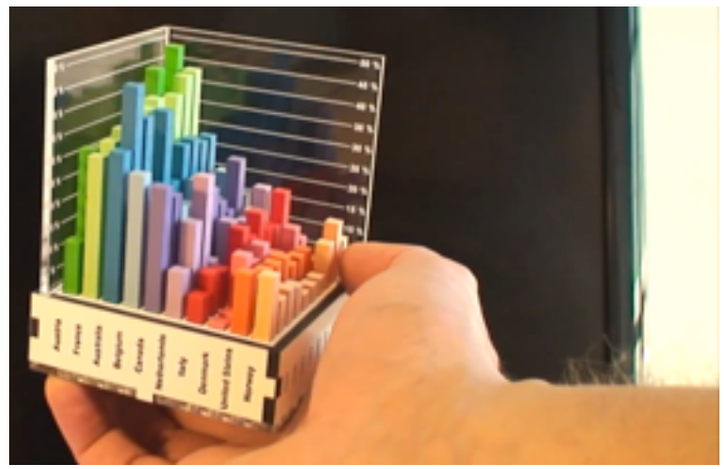
3D Mono



3D Stereo



Tangible



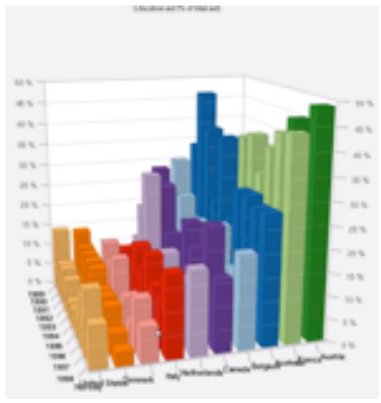
- Among possible explanation: Direct rotation

3D mono/stereo	**Tangible**
"Indirect" rotation (mapped to x and y axis of mouse)	"Direct" rotation

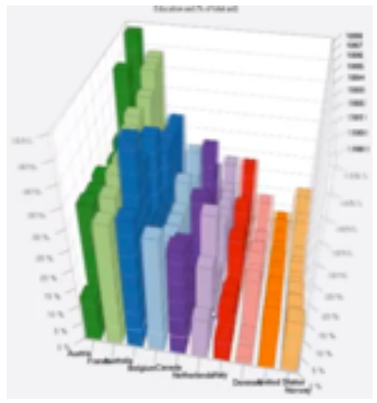
Tangibles User Interfaces

2D

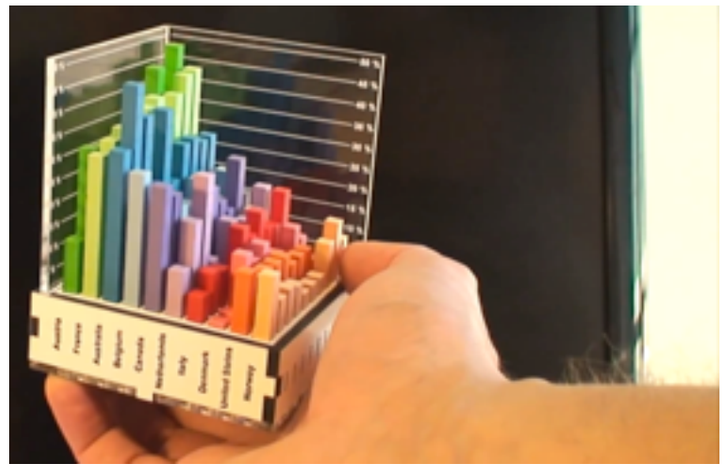
3D Mono



3D Stereo



Tangible



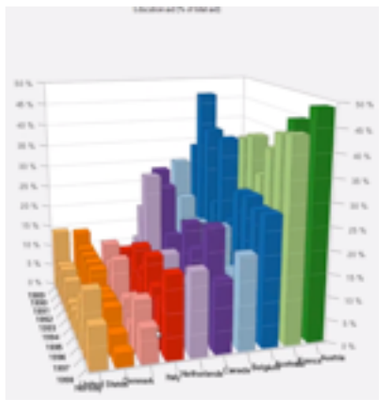
- Among possible explanation: Visual Realism

	3D mono/stereo	**Tangible**
Resolution	1920 x 1080 px for 23”	0.5mm
Stereoscopic cues (Images L and R different)	no / yes	yes
Accomodation cues	at screen distance	at any distance
Shading and shadows	computer-generated	natural
Texture	none	spray paint imperfections

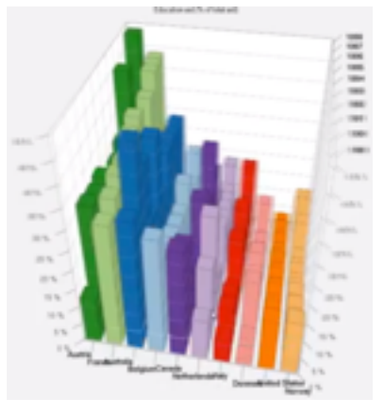
Tangibles User Interfaces

2D

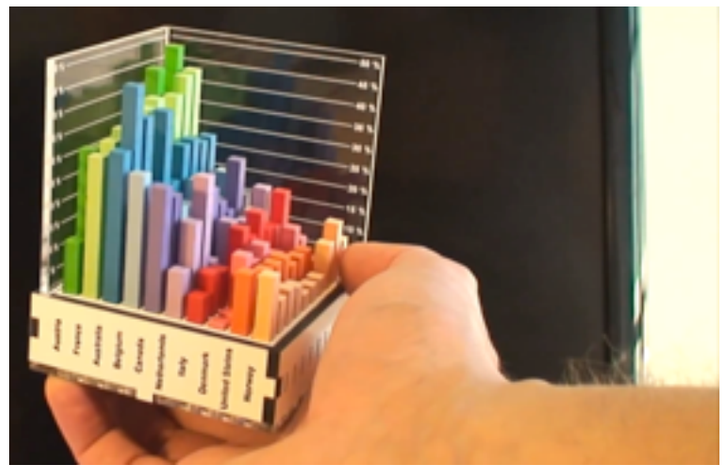
3D Mono



3D Stereo

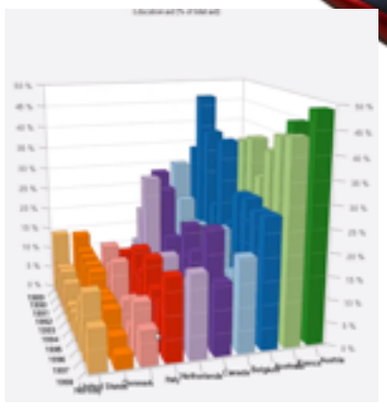


Tangible



- Impact of all possible explanations?
  - Touch & Proprioception?
  - Direct rotation?
  - Visual Realism?

Tangibles User Interfaces

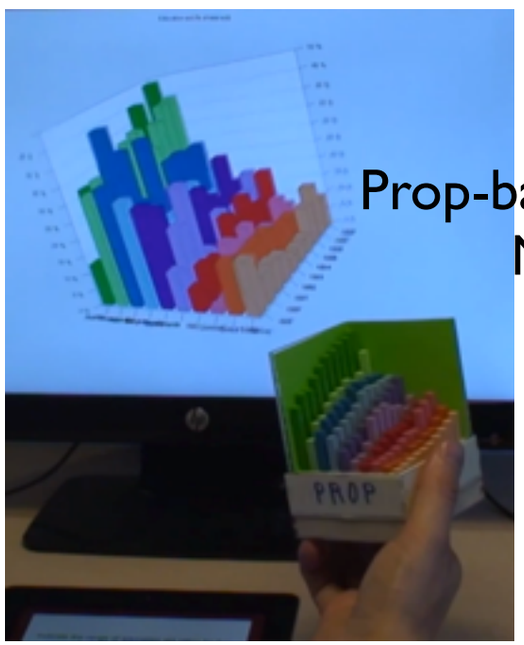


3D Mono &
Indirect mouse rotation &
No bar marking

Direct rotation

Tangible
Direct rotation
& Touch

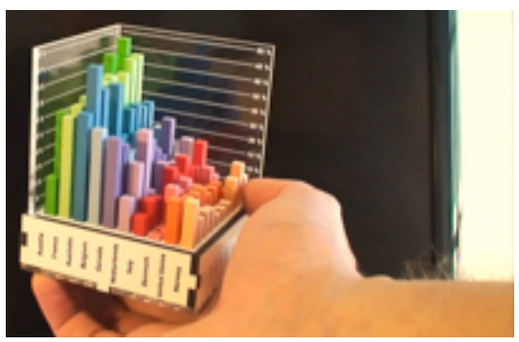
Touch &
Proprioception



3D Mono &
Prop-based direct rotation &
No bar marking

Visual realism

Tangible
Direct rotation &
No touch



Tangibles User Interfaces

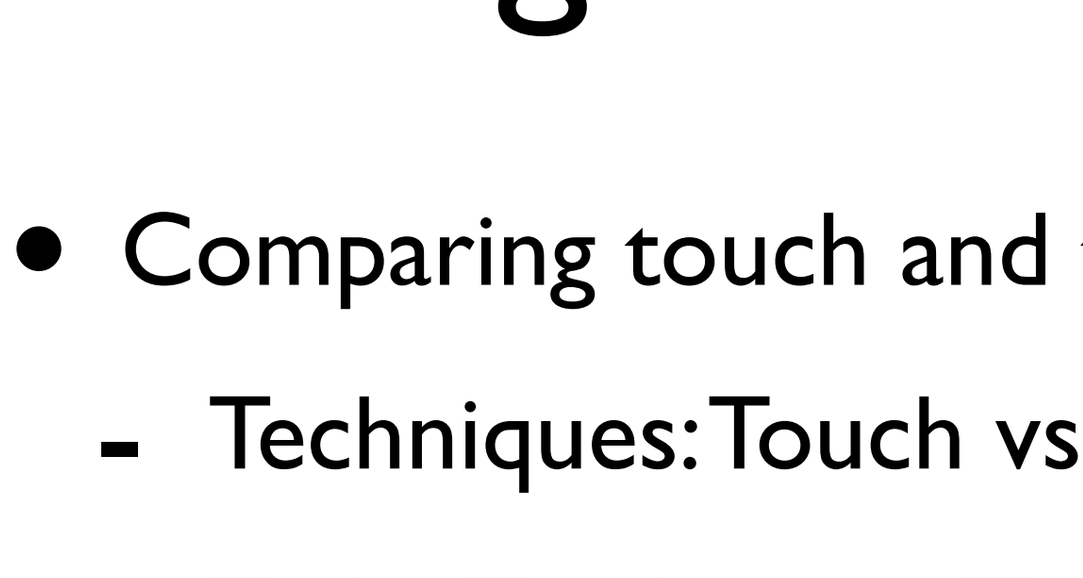
- Direct rotation: very little faster compared to indirect rotation
- Visual Realism: around 13% faster compared to on-screen
- Touch & Proprioception: around 15% faster than no touch
  - unload cognitive effort into a physical action

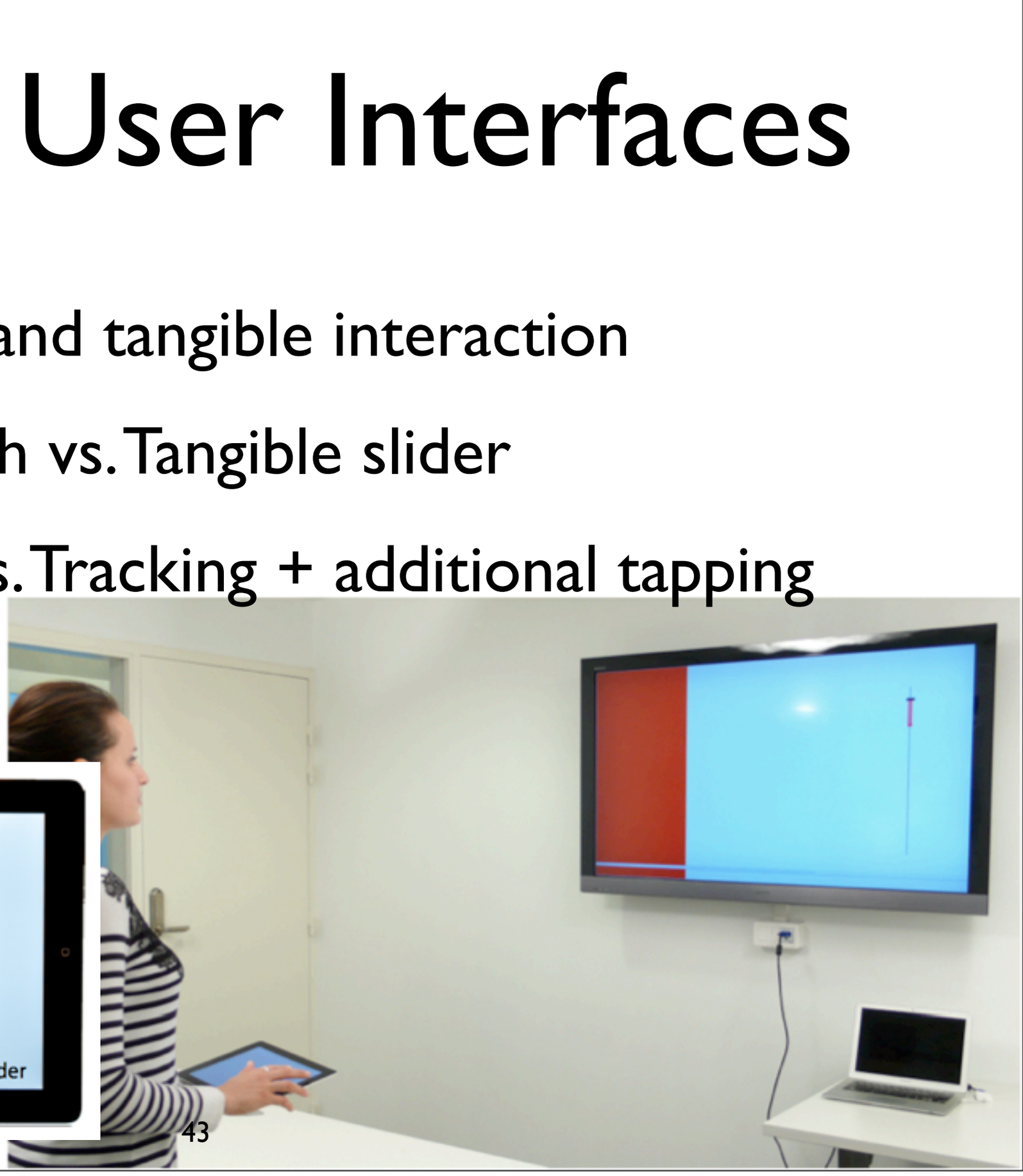
Tangible User Interfaces

- What are they good for?
  - Several experiments demonstrated their benefits

Tangible User Interfaces

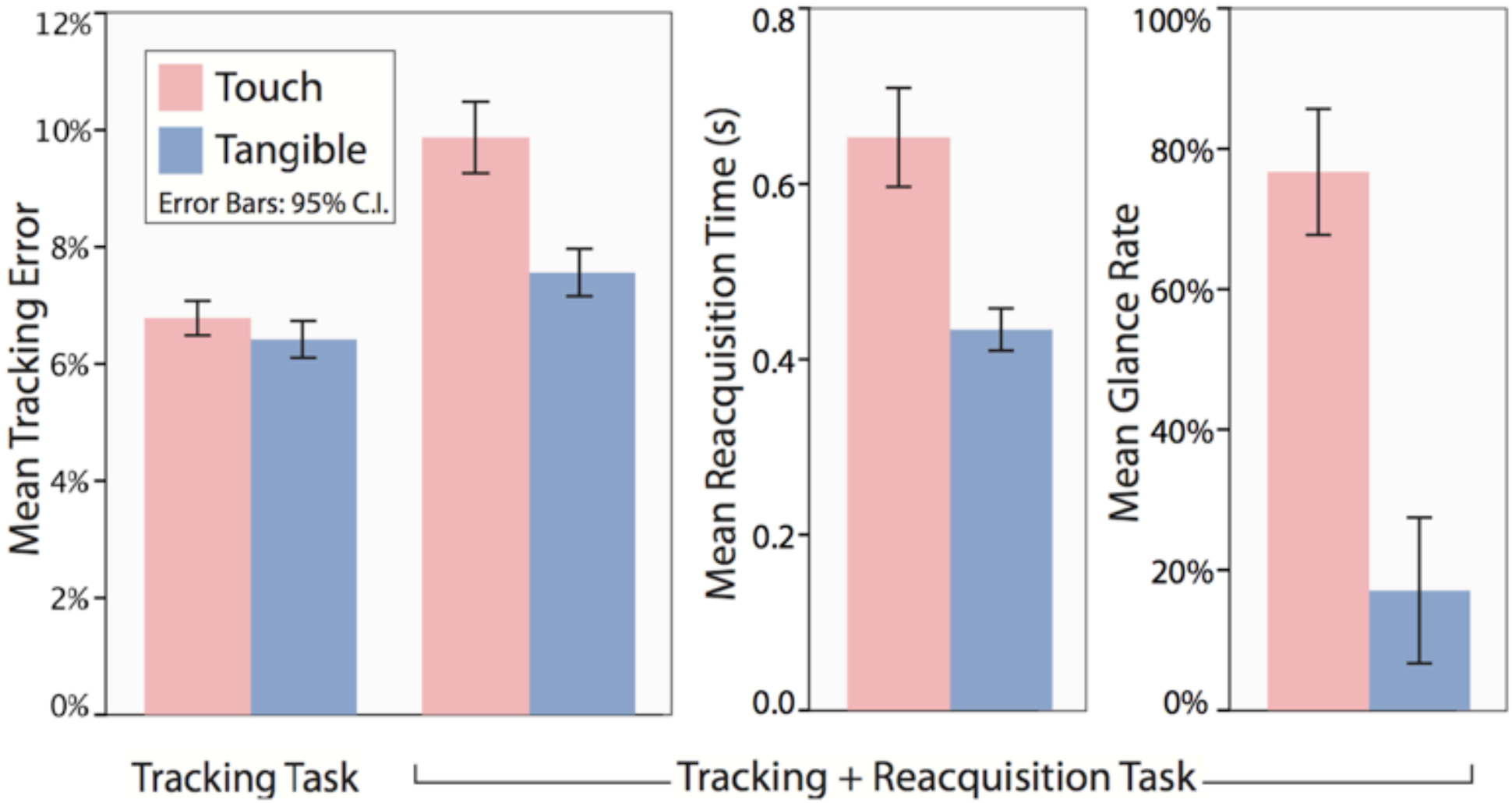
- Comparing touch and tangible interaction
  - Techniques: Touch vs. Tangible slider
  - Tasks: Tracking vs. Tracking + additional tapping





Tangible User Interfaces

- Comparing touch and tangible interaction

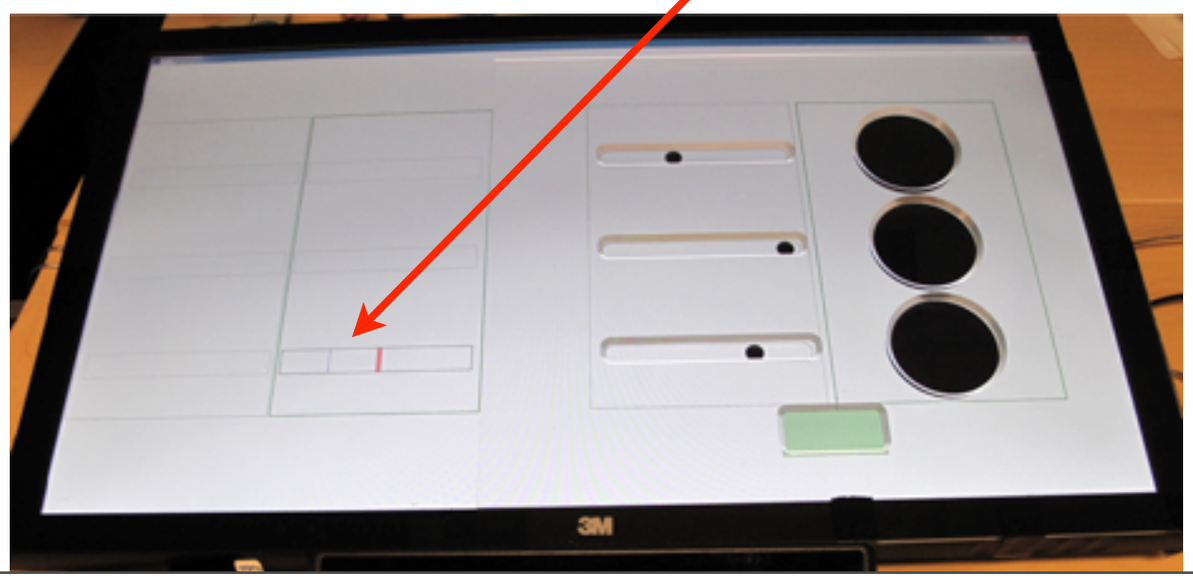


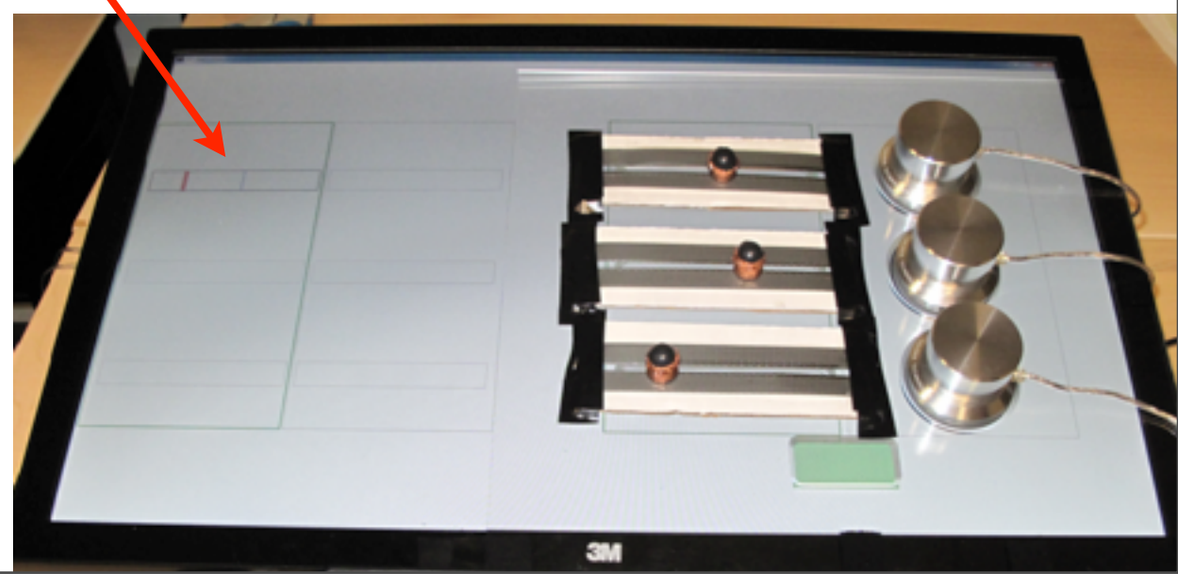
Tangible User Interfaces

- What are they good for?
  - Several experiments demonstrated their benefits

Tangible User Interfaces

- Comparing touch, overlay and tangible interaction
  - Tasks: set horizontal position of cursor

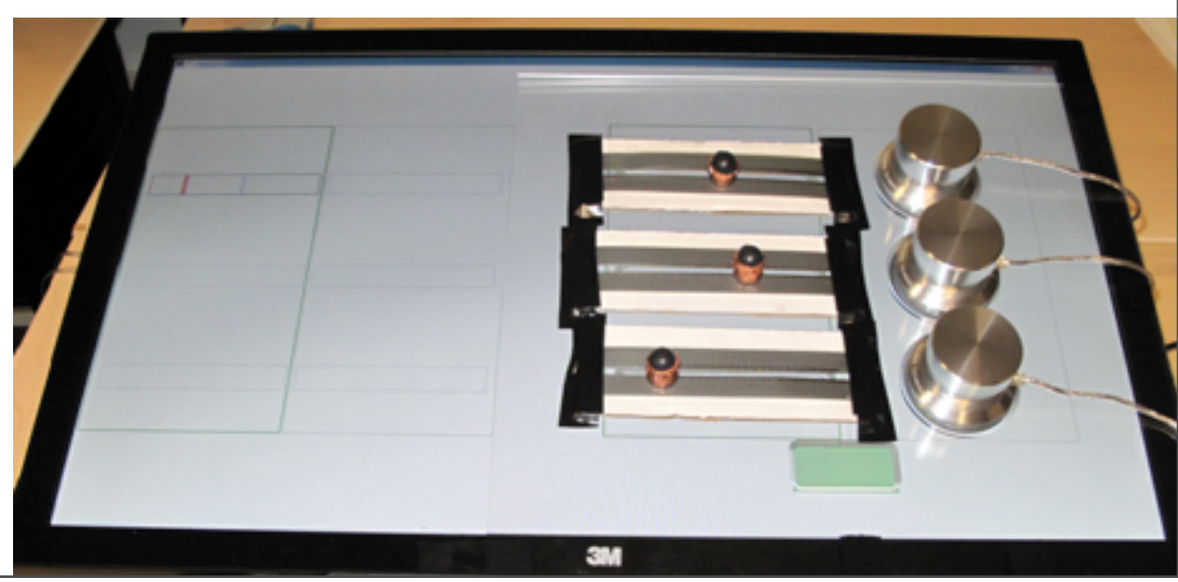




Tangible User Interfaces

- Comparing touch, overlay and tangible interaction
  - Tasks: set horizontal position of cursor

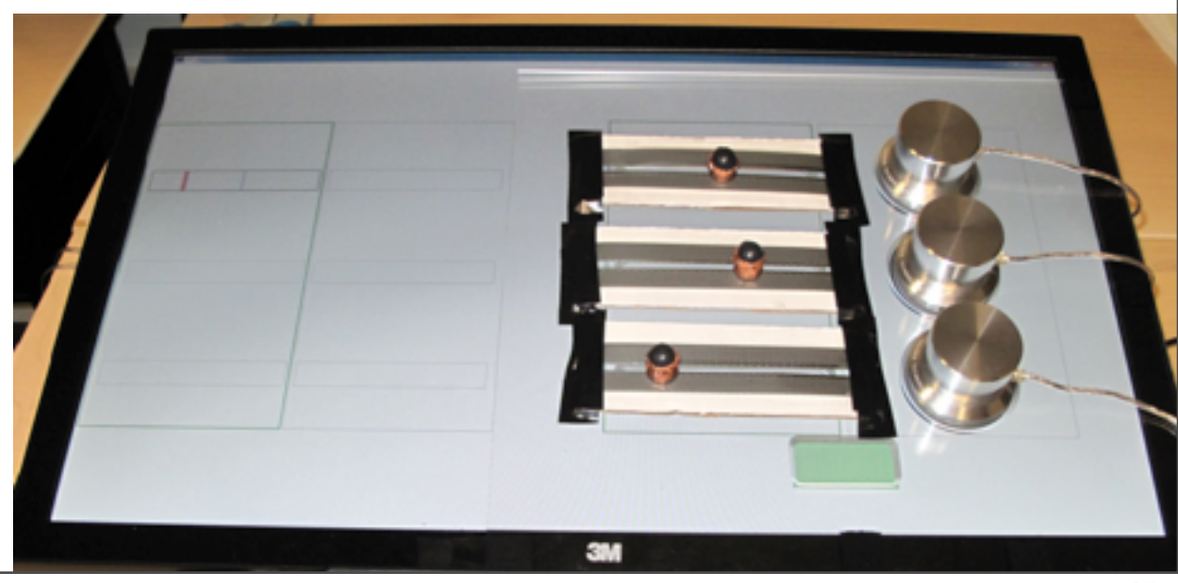
1. Press green button; Acquisition of required tool; Move towards and stay in target for 1 second;
2. Move cursor back and forth between two targets 5 times



Tangible User Interfaces

- Comparing touch, overlay and tangible interaction

	Touch	Overlay	Tangible
Slider			
Single-turn dial			
Multi-turn dial (Task 2 only: with CD gain 3x)			



Tangible User Interfaces

- Comparing touch, overlay and tangible interaction
  - Task 1: acquisition and movement

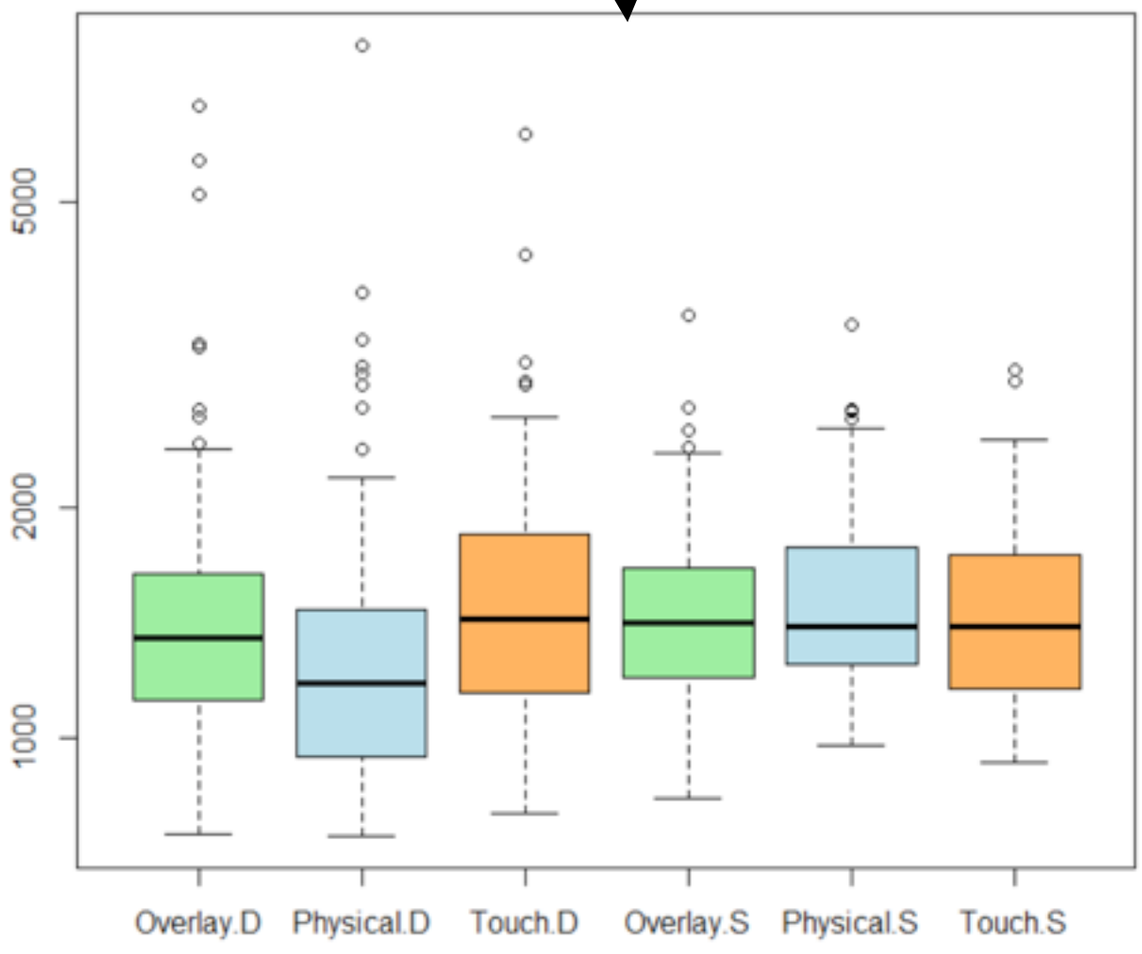
	Touch	Overlay	Tangible
Slider		?	
Single-turn dial			

  - Task 2: repetitive task

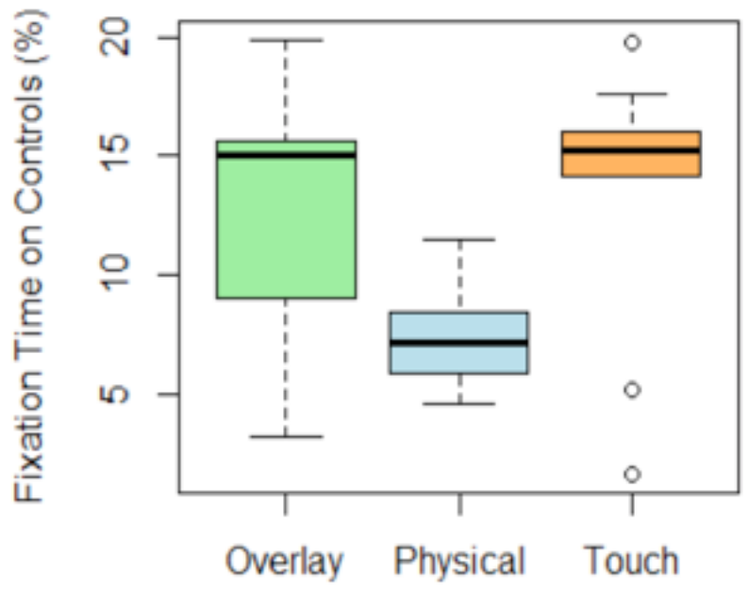
	Touch	Overlay	Tangible
Slider		?	
Single-turn dial			
Multi-turn dial (with CD gain 3x)			

Tangible User Interfaces

- Comparing touch, overlay and tangible interaction
  - Task 1: acquisition and movement

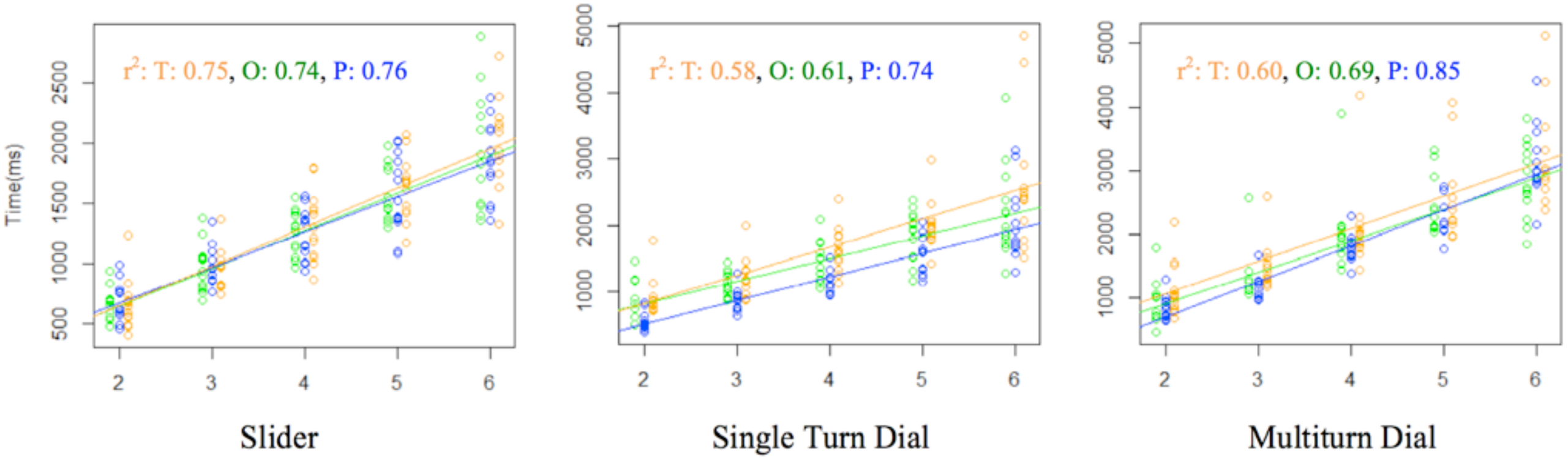


Problem with tangible sliders
("participants complained that they were wobbly and required some pressure")
?=> no difference found



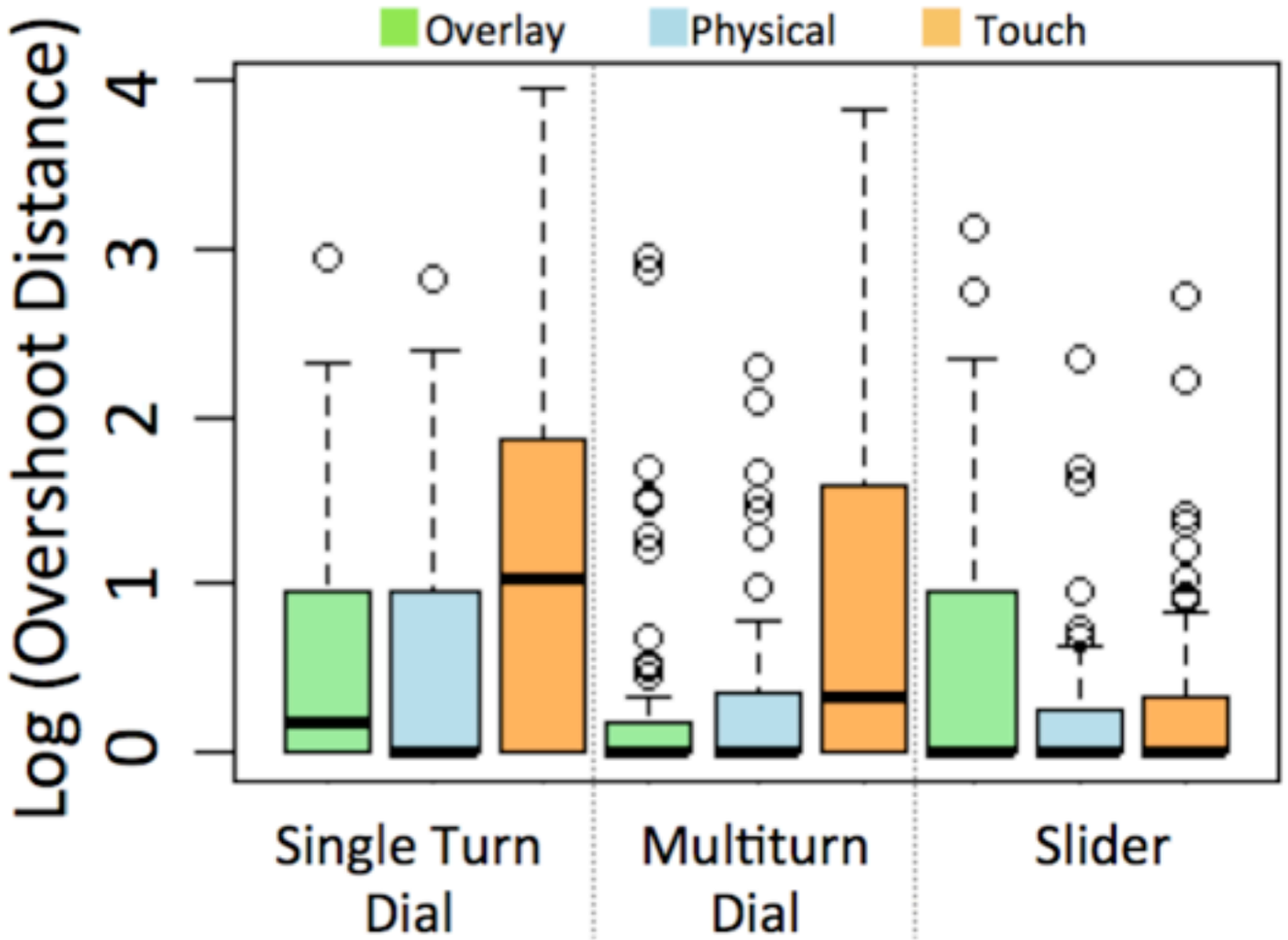
Tangible User Interfaces

- Comparing touch, overlay and tangible interaction
  - Task 1: Repetitive movement



Tangible User Interfaces

- Comparing touch, overlay and tangible interaction
  - Task 1: Repetitive movement



Tangible User Interfaces

- What are their limitations?

Graphical > Tangible?

- Dynamicity, Flexibility
- Rapidity
- Price

Graphical > Tangible?

- Reality based interaction
  - Compromise with software when it brings benefit

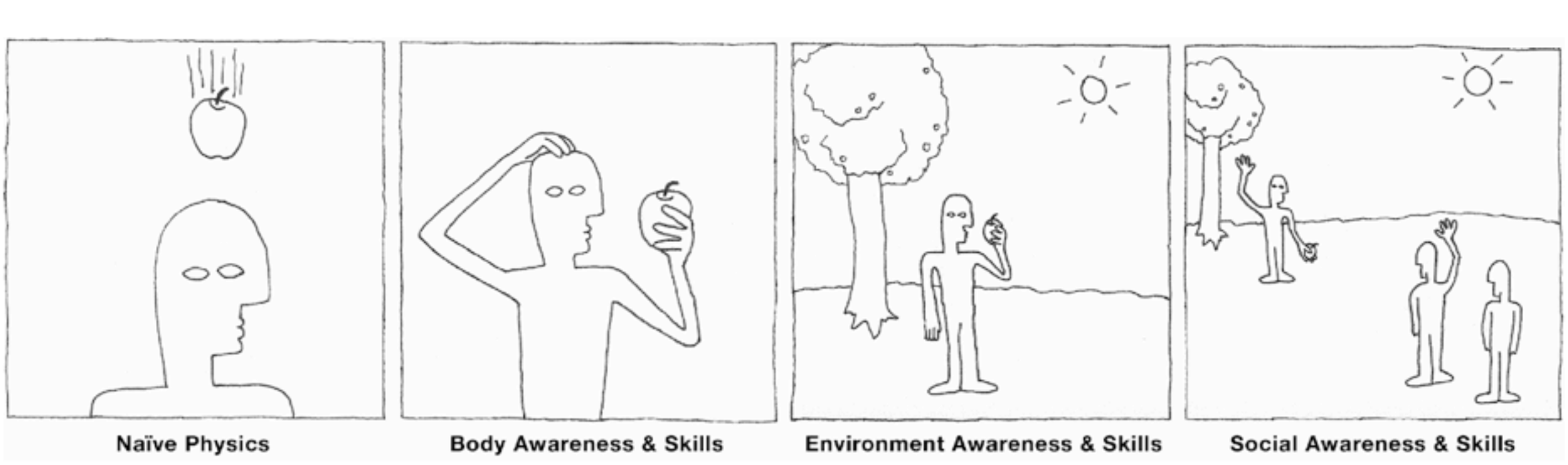
http://dl.acm.org/citation.cfm?doid=1357054.1357089

Reality Based Interaction

- Interface design
  - build on 4 themes (= human capabilities) from the “real” world
  - compromise with 6 tradeoffs in order to reach design goal

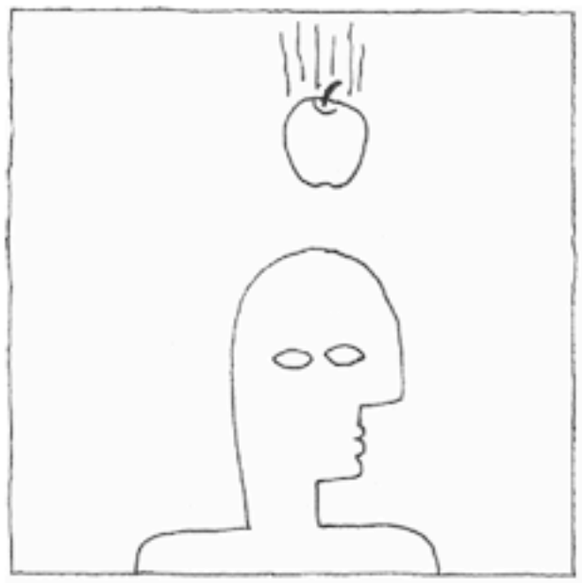
Reality Based Interaction

- Four themes from the "real" world



Reality Based Interaction

- Naïve physics: Basic knowledge about the physical world



Naïve Physics

E.g., gravity, friction, velocity

Example of interfaces using users' knowledge of naive physics?

Reality Based Interaction

- Body Awareness & Skills: Understanding of own body

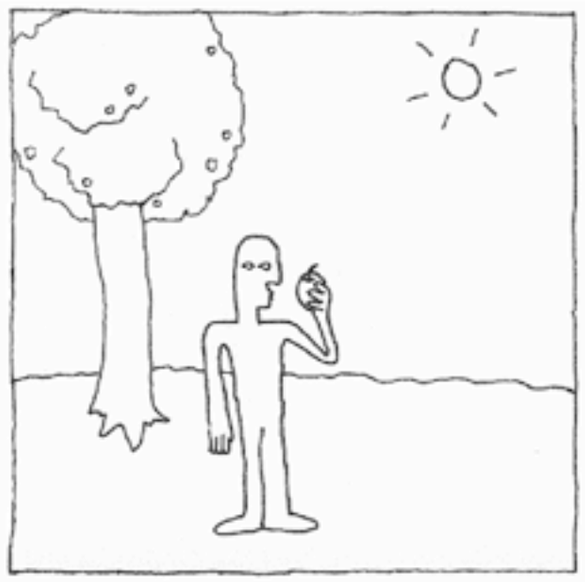
Body Awareness & Skills

E.g., relative position of body parts, range of motion, skills to coordinate movements (to walk, kick a ball)

Example of interfaces using users' body awareness and skills?

Reality Based Interaction

- Environment Awareness & Skills: Understanding of clues from environment



Environment Awareness & Skills

E.g., horizon gives a sense of directional information, lighting and shadow provide depth cues

Example of interfaces using users' environment awareness and skills?

Reality Based Interaction

- Social Awareness & Skills

Social Awareness & Skills

E.g., verbal and non-verbal communication, exchange objects, ability for collaboration

Example of interfaces using users' social awareness and skills?

Reality Based Interaction

- Six tradeoffs
  - Expressive power: ability to perform a variety of tasks within the application domain
  - Efficiency: ability to perform a task rapidly
  - Versatility: ability to perform many tasks from different application domains
  - Ergonomics: ability to perform a task without physical injury or fatigue
  - Accessibility: ability to perform a task when handicapped
  - Practicality: (designers) ability to produce the system

Reality Based Interaction

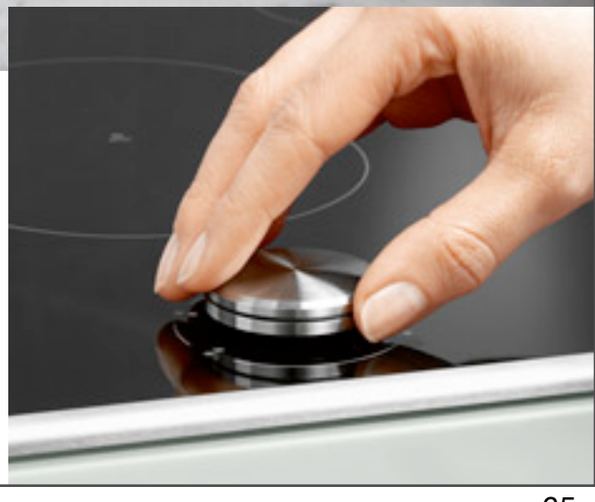
- Case study: URP http://vimeo.com/48600713
- What themes does URP use?
  - Naive Physics
  - Body
  - Environment
  - Social Awareness

Reality Based Interaction

- What does URP sacrifice for which benefit?
  - Expressive power
  - Efficiency
  - Versatility
  - Ergonomics
  - Accessibility
  - Practicality

Graphical > Tangible?

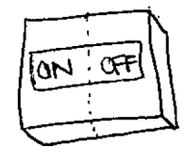
- Software mouse+touch GUI took over
- Tangible might be coming back
  - E.g., induction hub with removable magnetic tangible knob
- New and Open research areas that bring tangibles closer to software

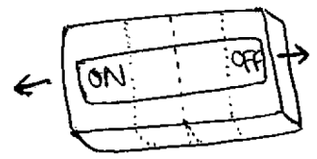


Dynamicity & Flexibility

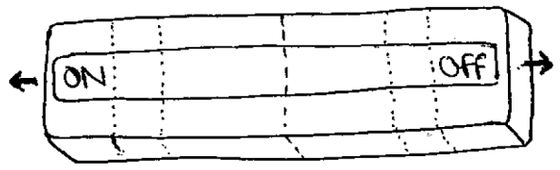
- A Reconfigurable Ferromagnetic Input Device
  - https://www.youtube.com/watch?v=UTmOPY9icwQ
- SandScape
  - http://vimeo.com/44538789
- Illuminating Clay
  - https://vimeo.com/44537533

Dynamicity & Flexibility

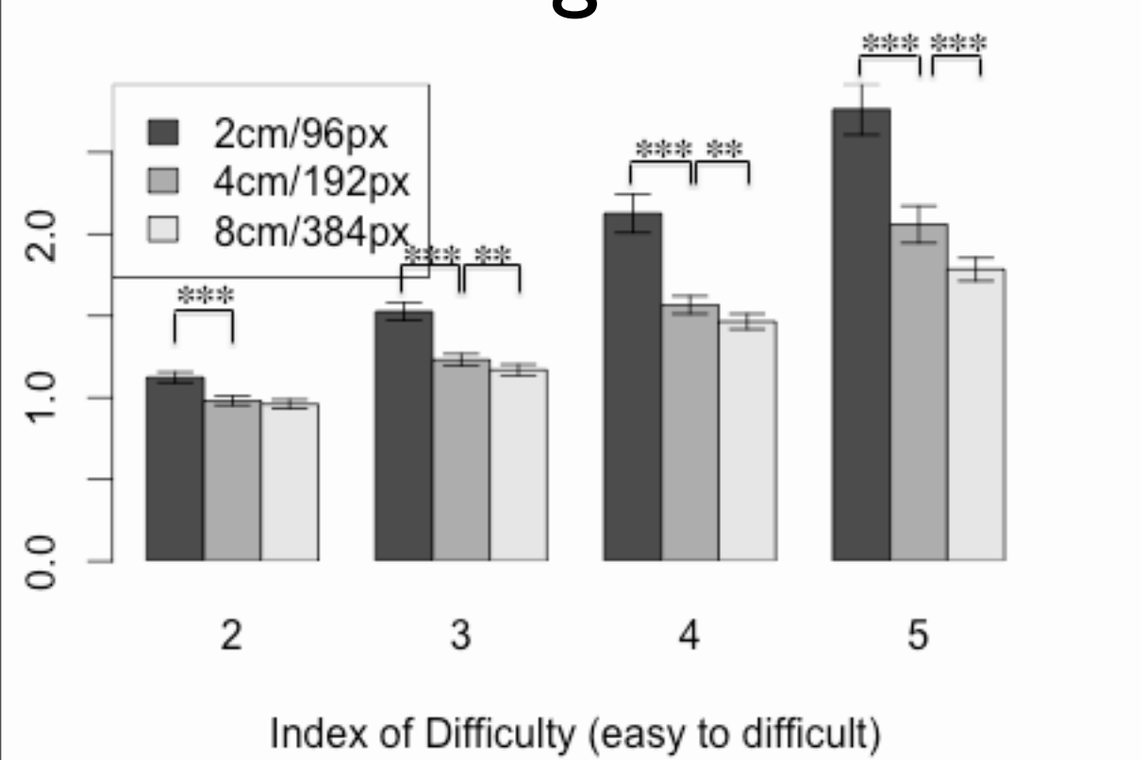




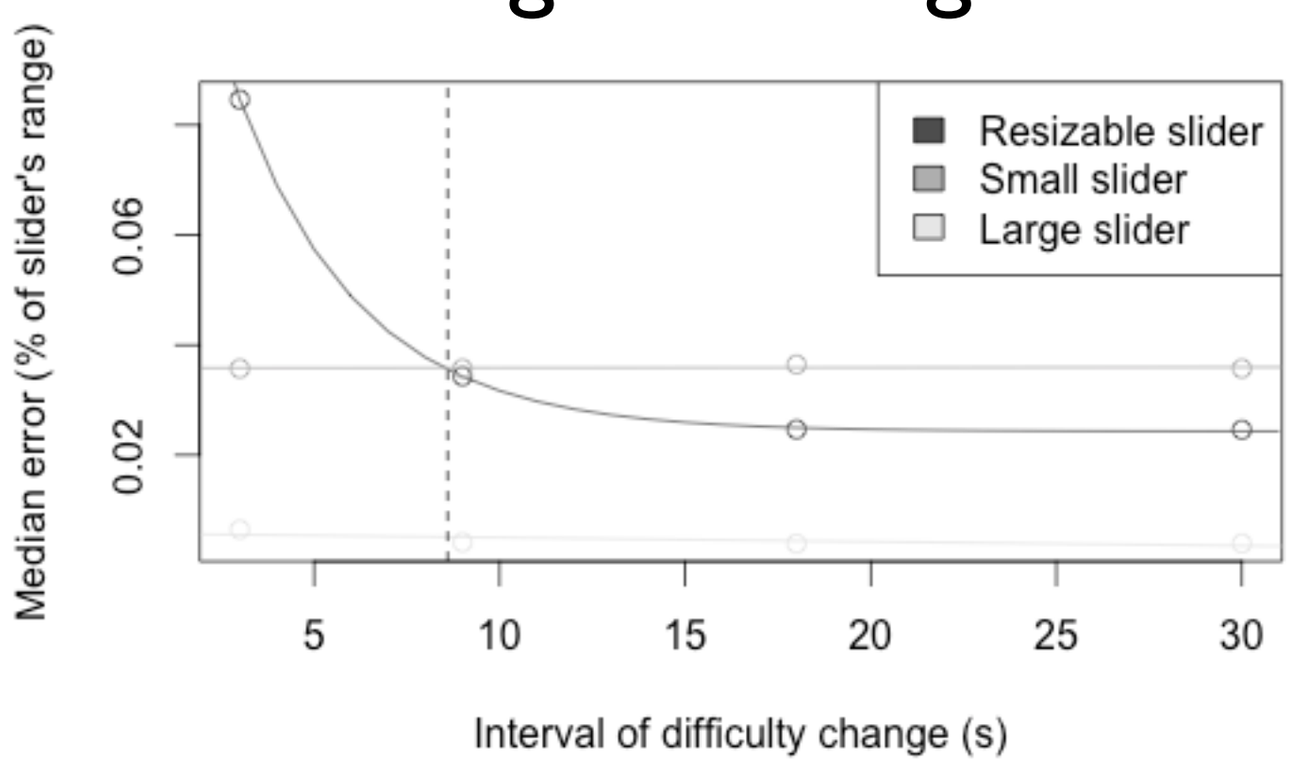
- Shape-changing slider (ongoing work)



Pointing task



Resizing+Tracking task



Dynamicity & Flexibility

- Acuated workBench
- PICO
  - http://vimeo.com/44539342
- Dynamically changeable buttons
  - http://www.youtube.com/watch?v=Smai_Z_galE
- Jamming UI
- Use of shape-memory alloys
  - e.g. in Shutters http://vimeo.com/4265211
- ZeroN
- Shape-changing display:
  - https://vimeo.com/79179138
- Shape-changing display for remote collaboration:
  - https://vimeo.com/108402837
- Weight Changing Interface
  - https://vimeo.com/87068584
- Composite materials for Shape-Change

Future of Tangible Interaction

- Flexibility will not be software's monopoly and will reach Tangibles
  - Claytronics video
- Radical Atoms & Perfect Red
  - https://vimeo.com/61141209