Advanced Human-Computer Interaction:
Tangible Interaction

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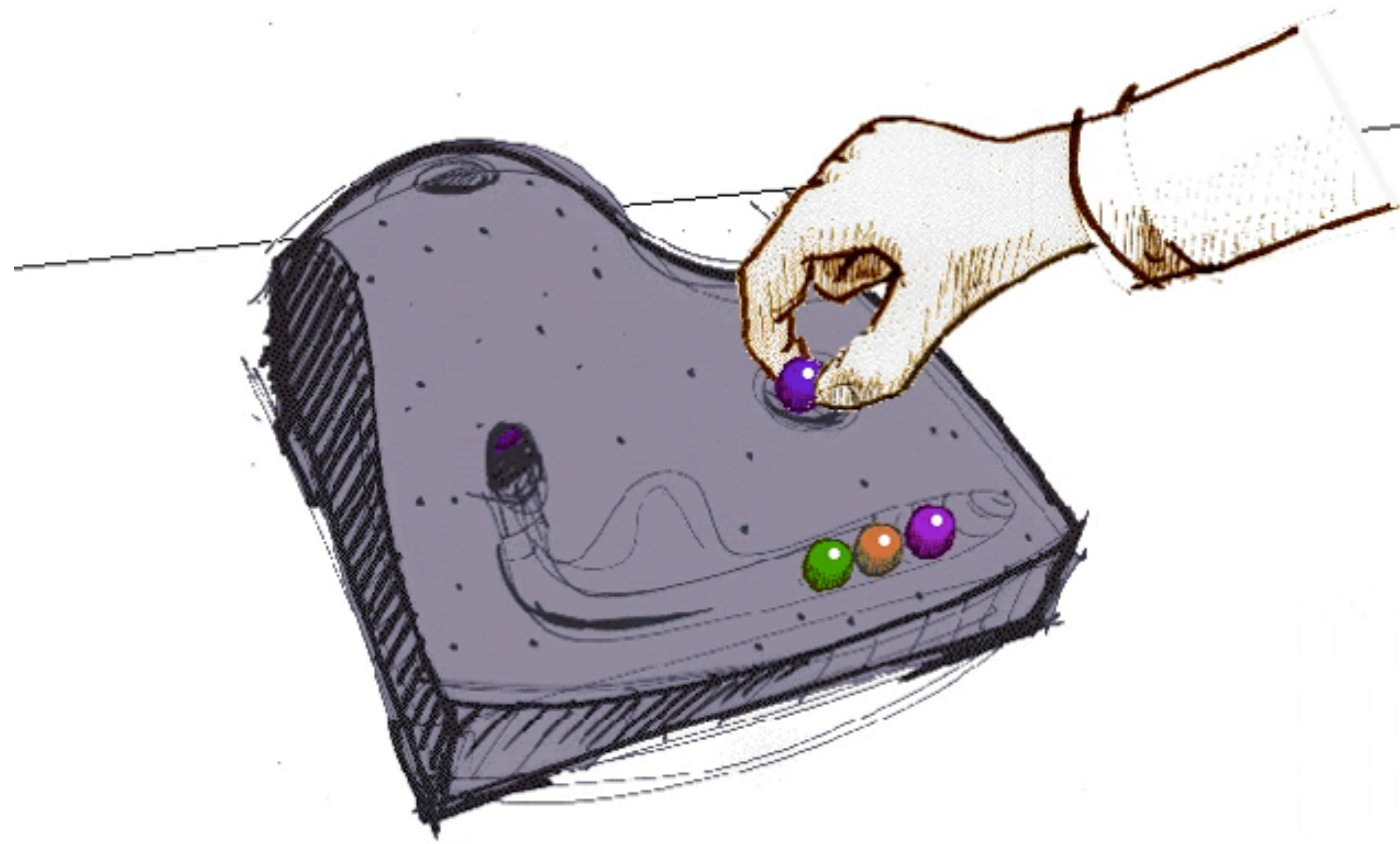
Course objectives

- 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?

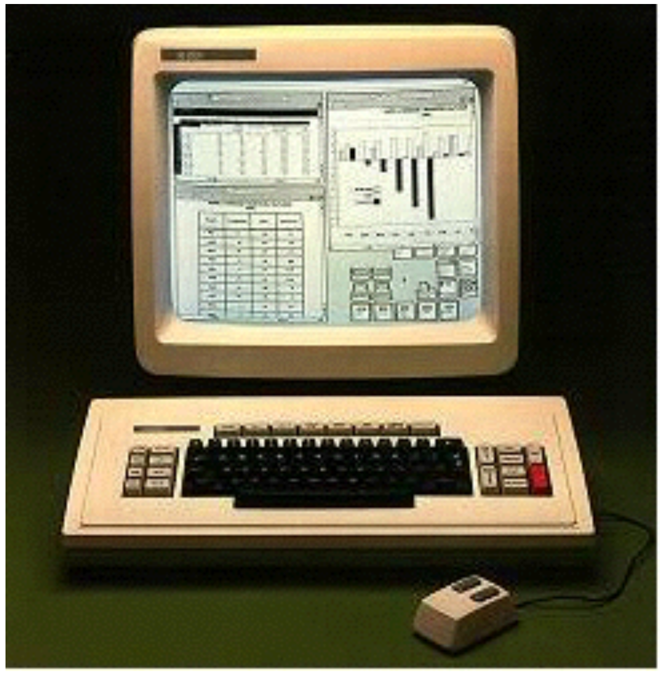
Tangible User Interfaces: What are they?

Interfaces involving physical objects that can be grasped



Example:
Durell Bishop's
Answering Machine

Tangible User Interfaces: What are they?



Graphical User Interfaces

interfaces usually limited to std screen+keyboard+mouse

Tangible User Interfaces: What are they?

Virtual Reality Interfaces

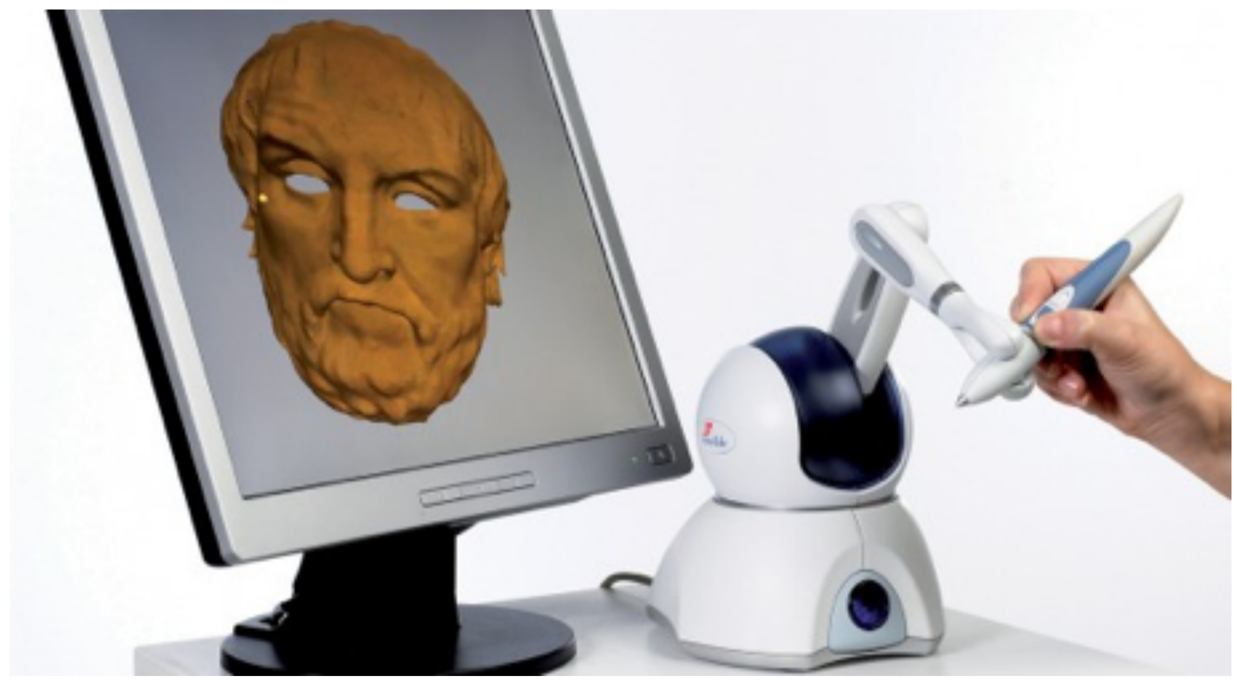
interfaces to immerse the user in a digitally generated world

Tangible User Interfaces: What are they?

Augmented Reality (AR) and Augmented Virtuality (AV)

Tangible Interfaces belong to AR+AV

Tangible User Interfaces: What are they?



Haptic Interaction
Tangible Interfaces belong to Haptic:
Both involve touch and manipulation,
but haptic usually not passive

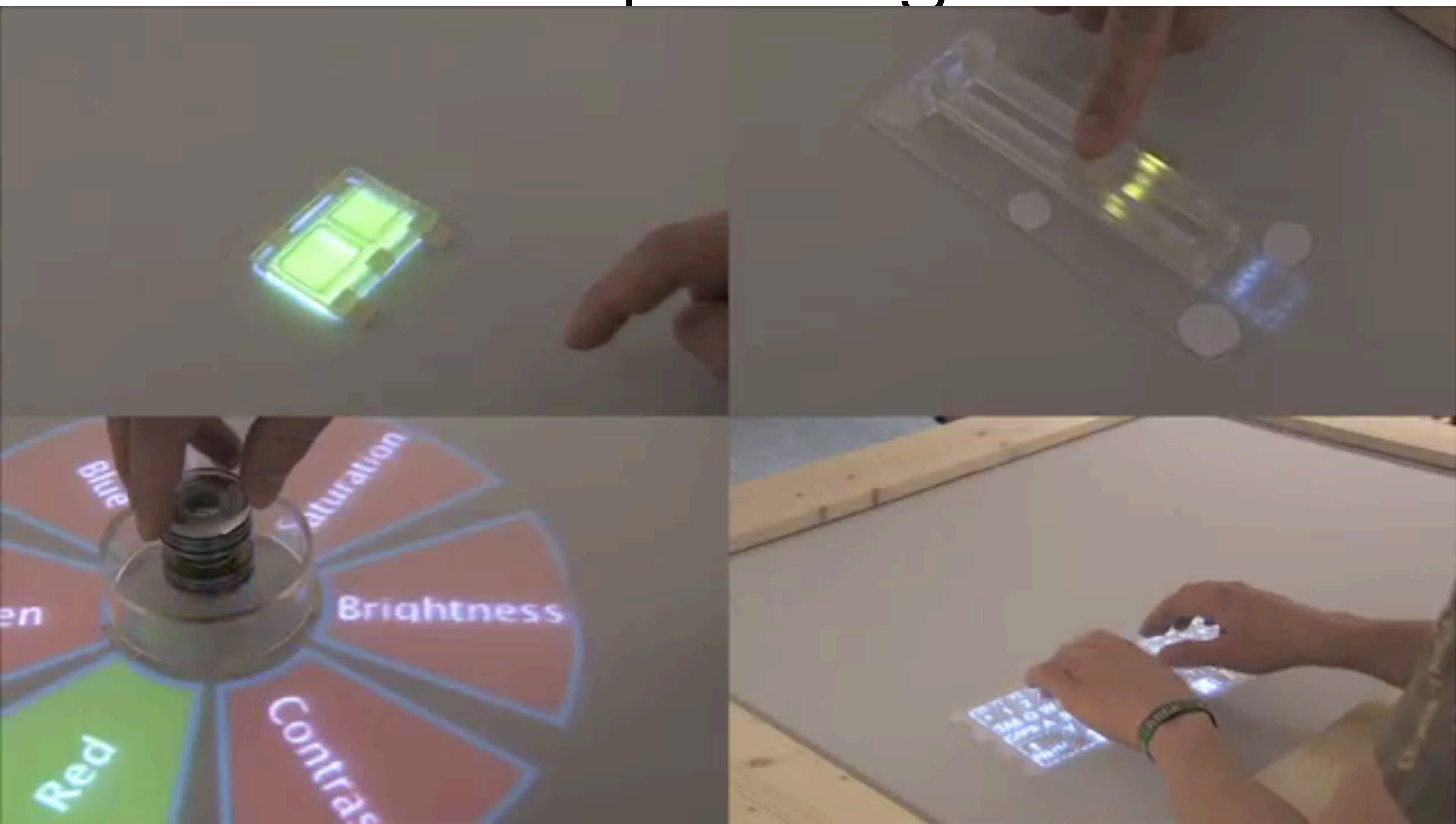
Tangible User Interfaces: What are they?

Internet of Things

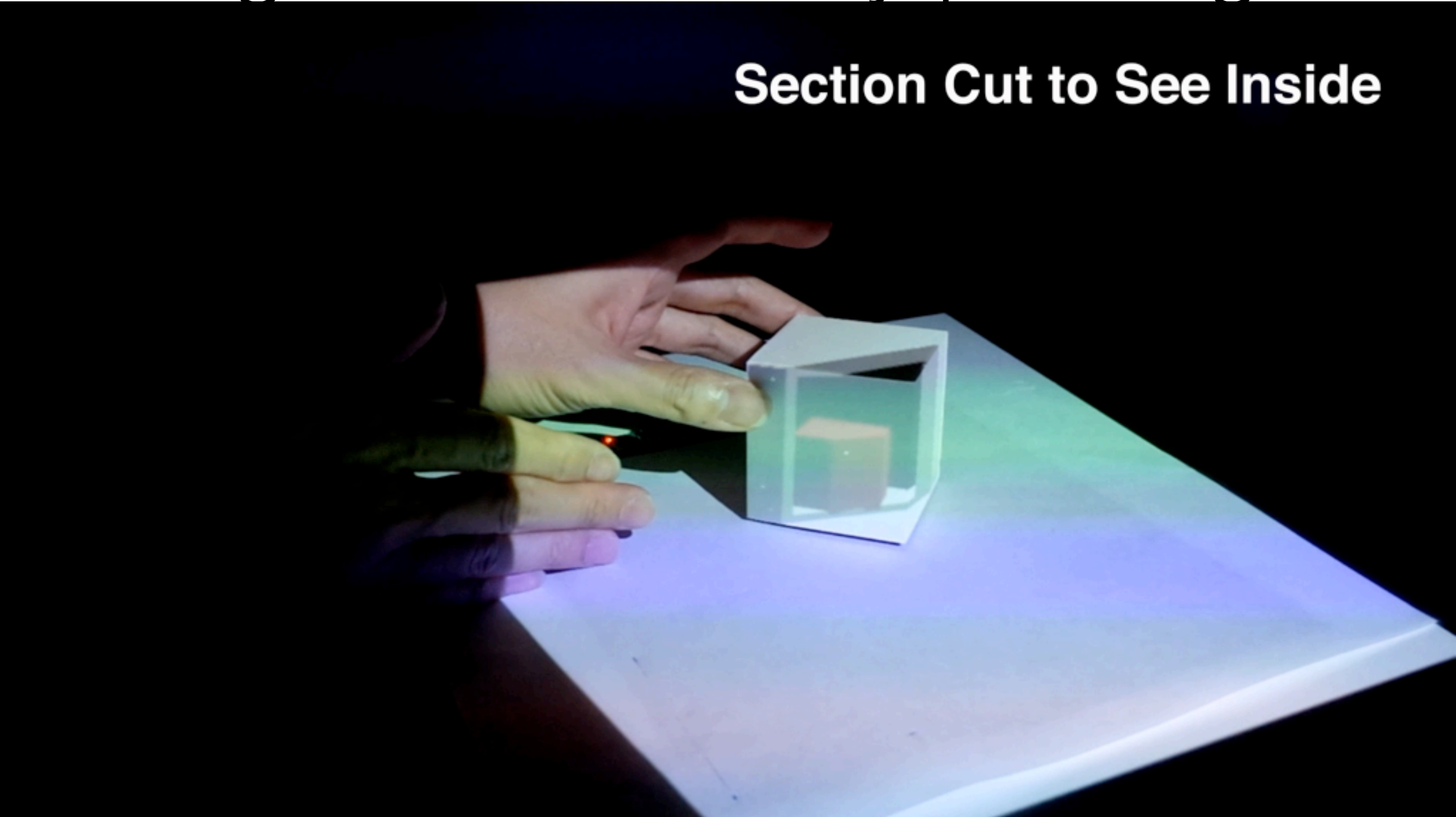
TUI not necessarily connected to Internet

If so, can be through a computer

Spread:
GUI paradigm

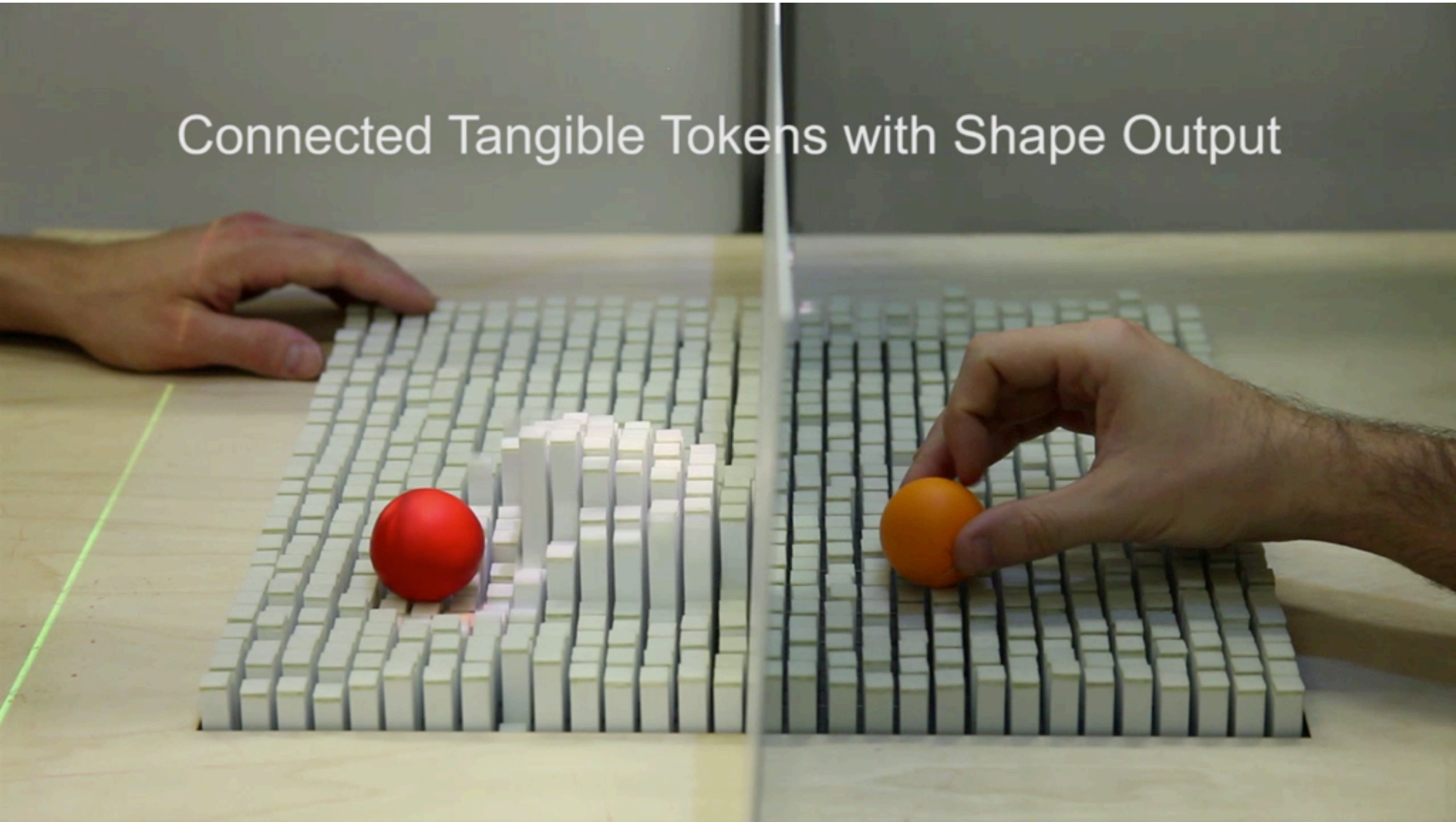


Spread:
Augmented Reality paradigm



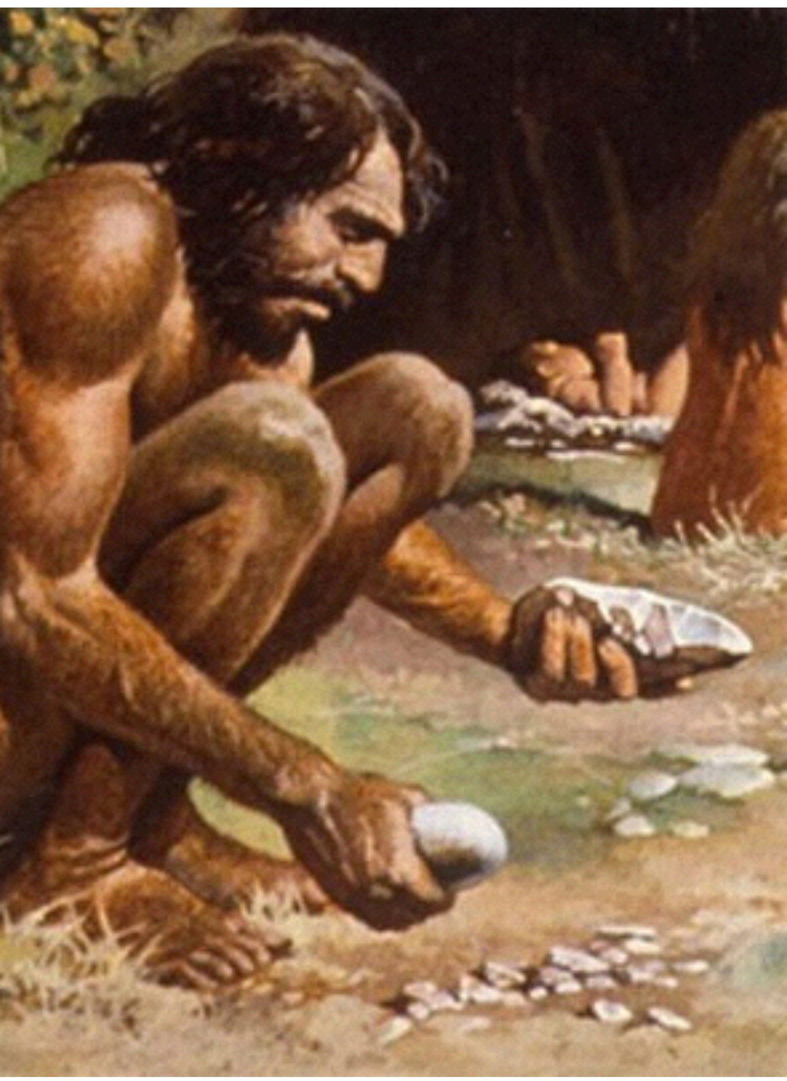
Spread: visualisation tasks

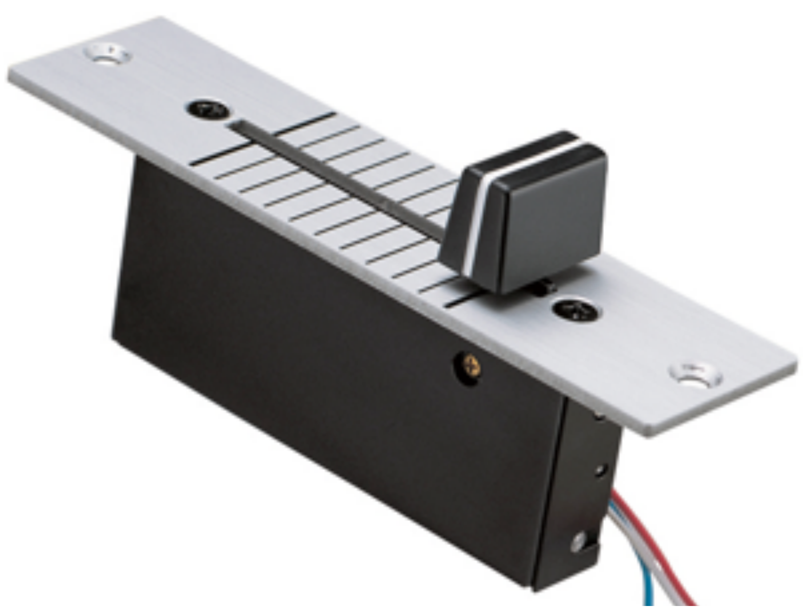
Spread: Remote collaboration tasks



What is their story?

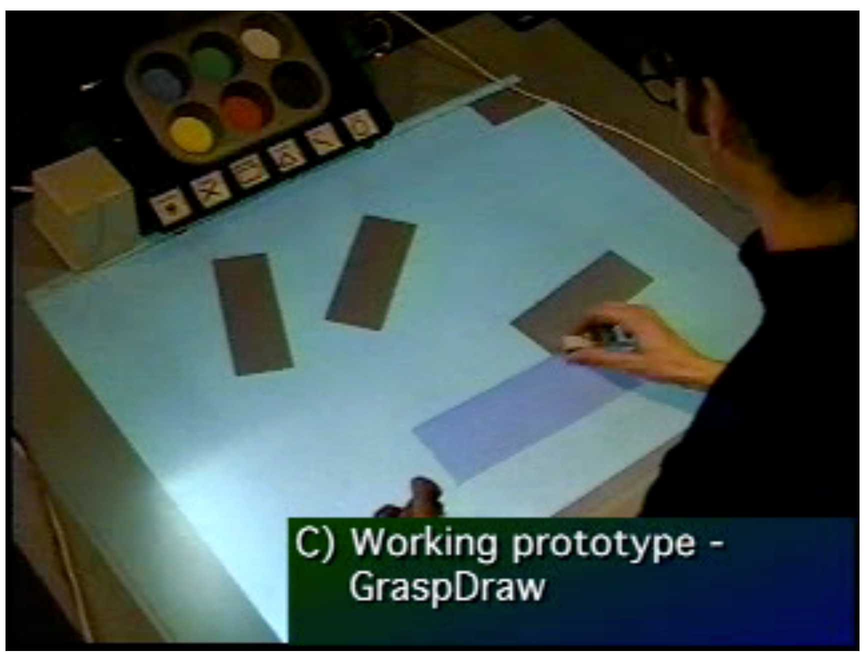
Manipulation of tangible tools has always been here...





... and is still here

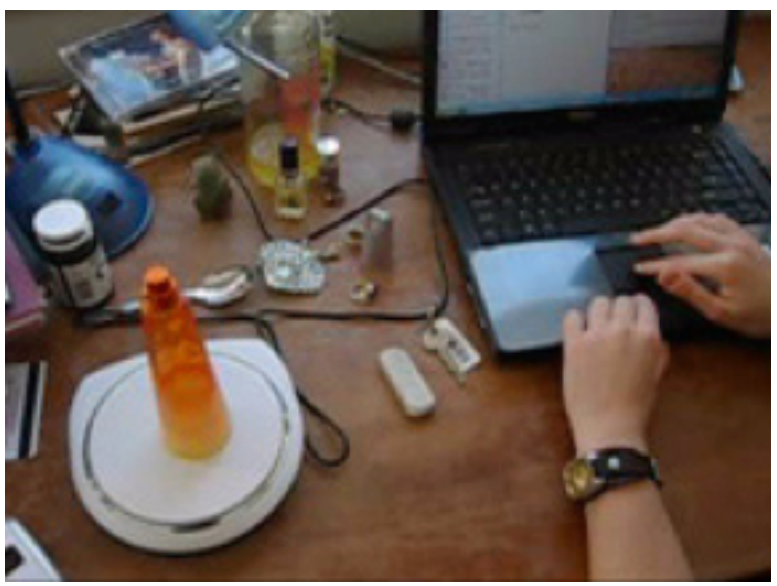
Seminal papers

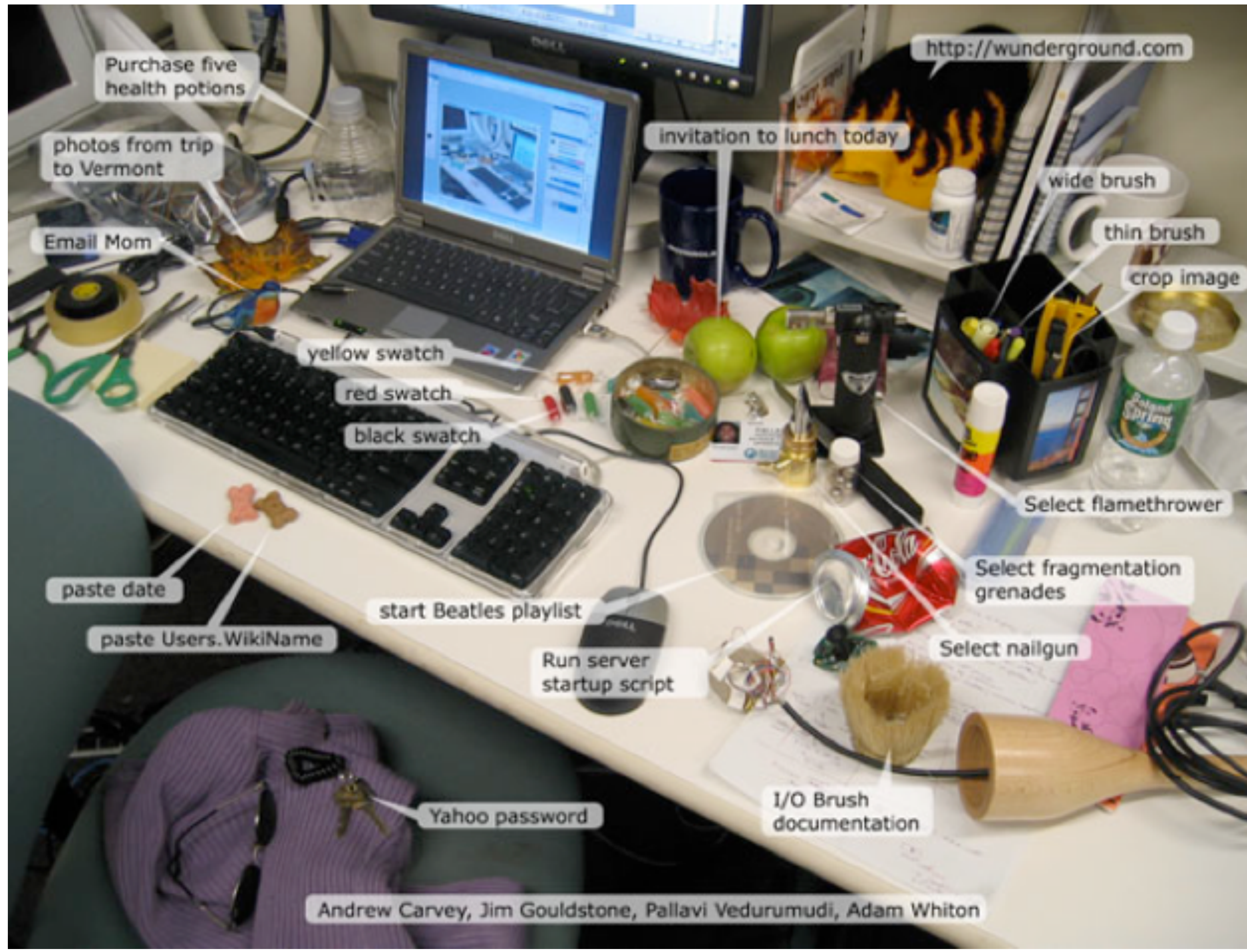


Early works on Tangible User Interfaces

- 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

Example of Tangible User Interfaces



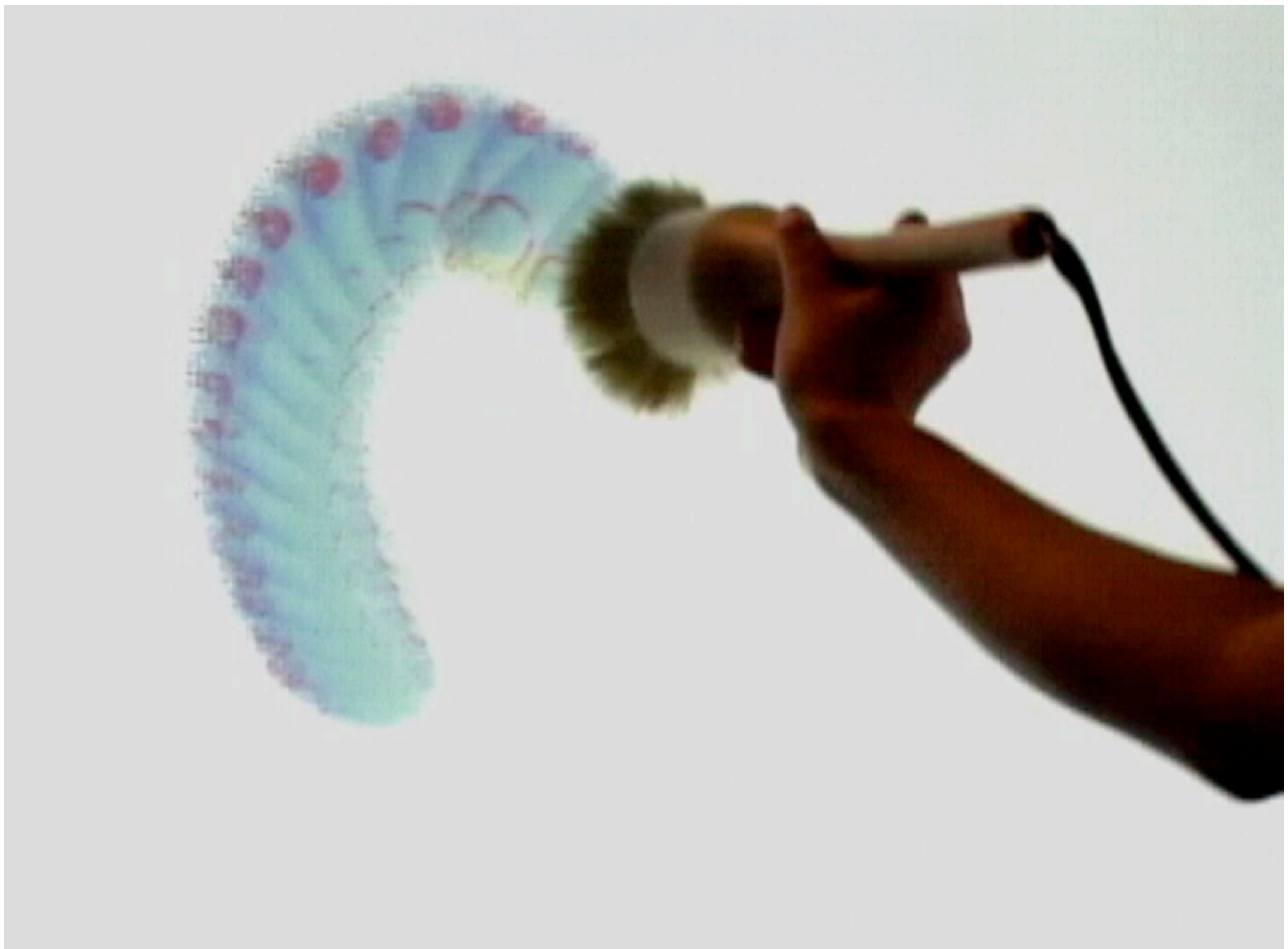


http://dl.acm.org/citation.cfm?doid=1125451.1125582

Example of Tangible User Interfaces

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

Example of Tangible User Interfaces



I/O Brush

Tangible User Interfaces
What are they good for?

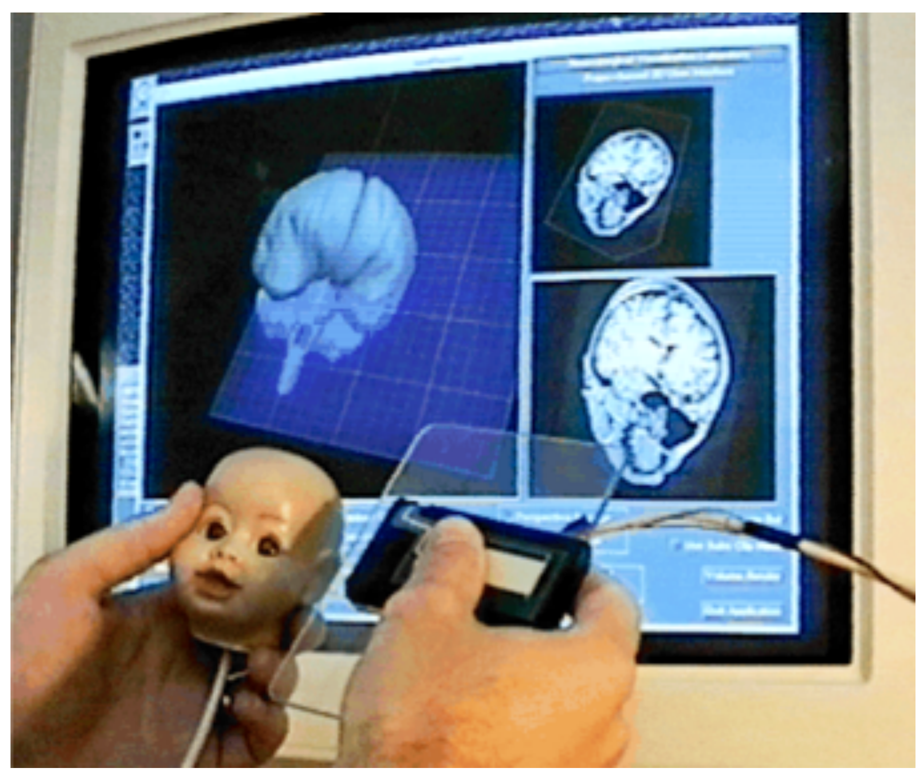
Tangible User Interfaces
What are they good for?

- **Interaction embodied**
  in the physical world of the user:
  Physical User & Physical Interface

- **Performance**:
  passive haptic feedback

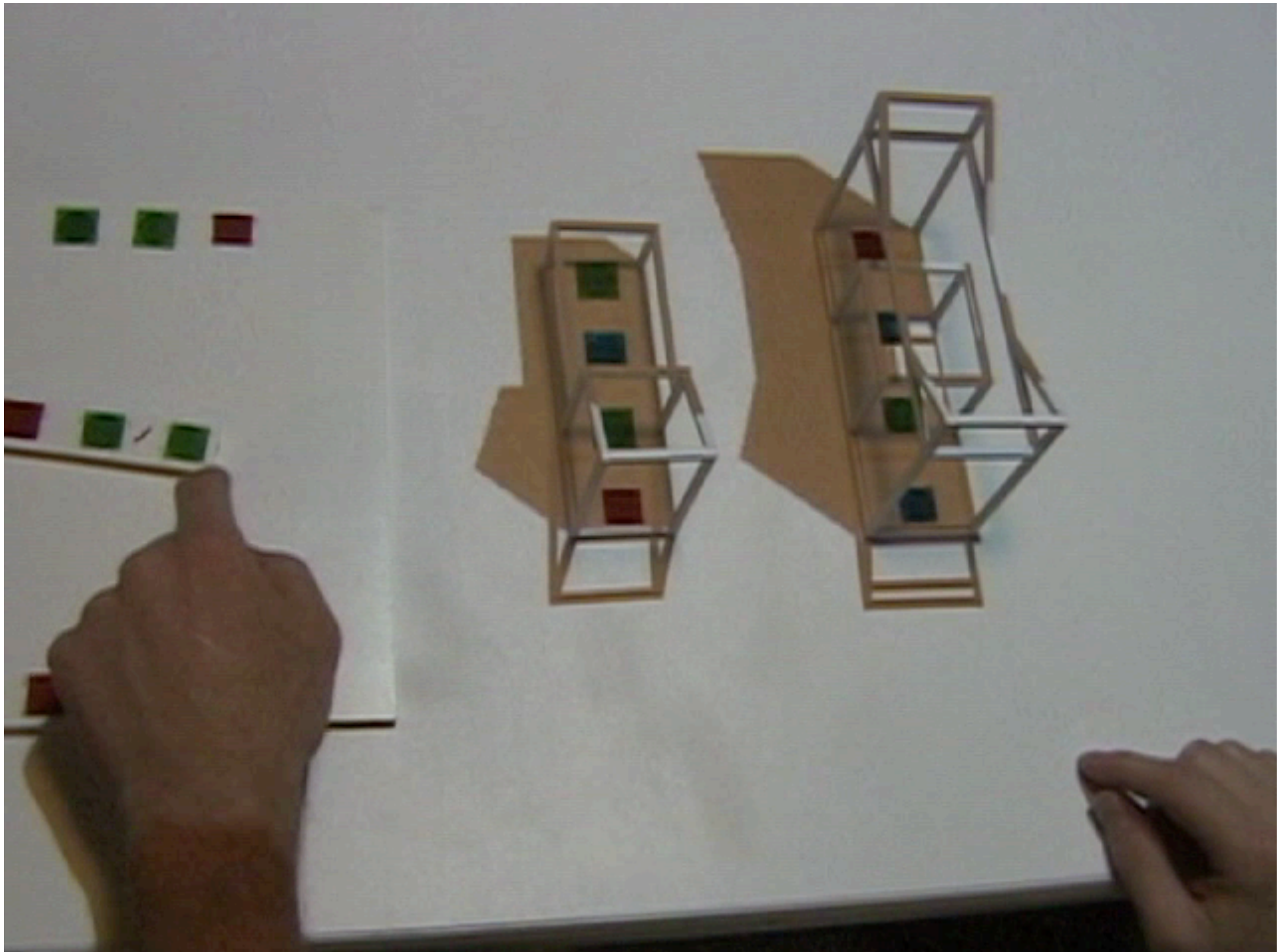
Embodied interaction

Object (prop) to interact at a distance with GUI



Embodied interaction

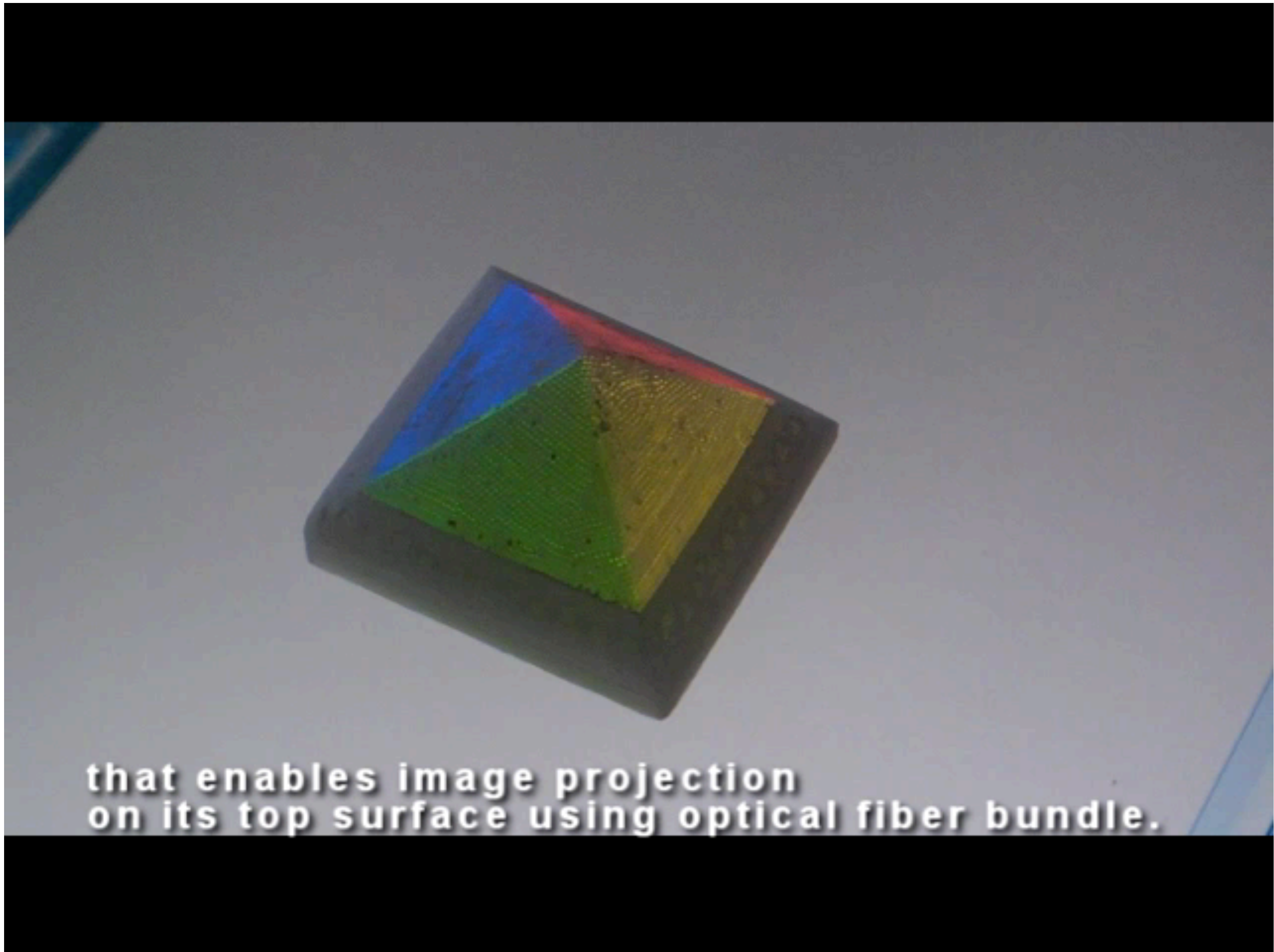
Tangible and overlaid projection



Example: URP

Embodied interaction

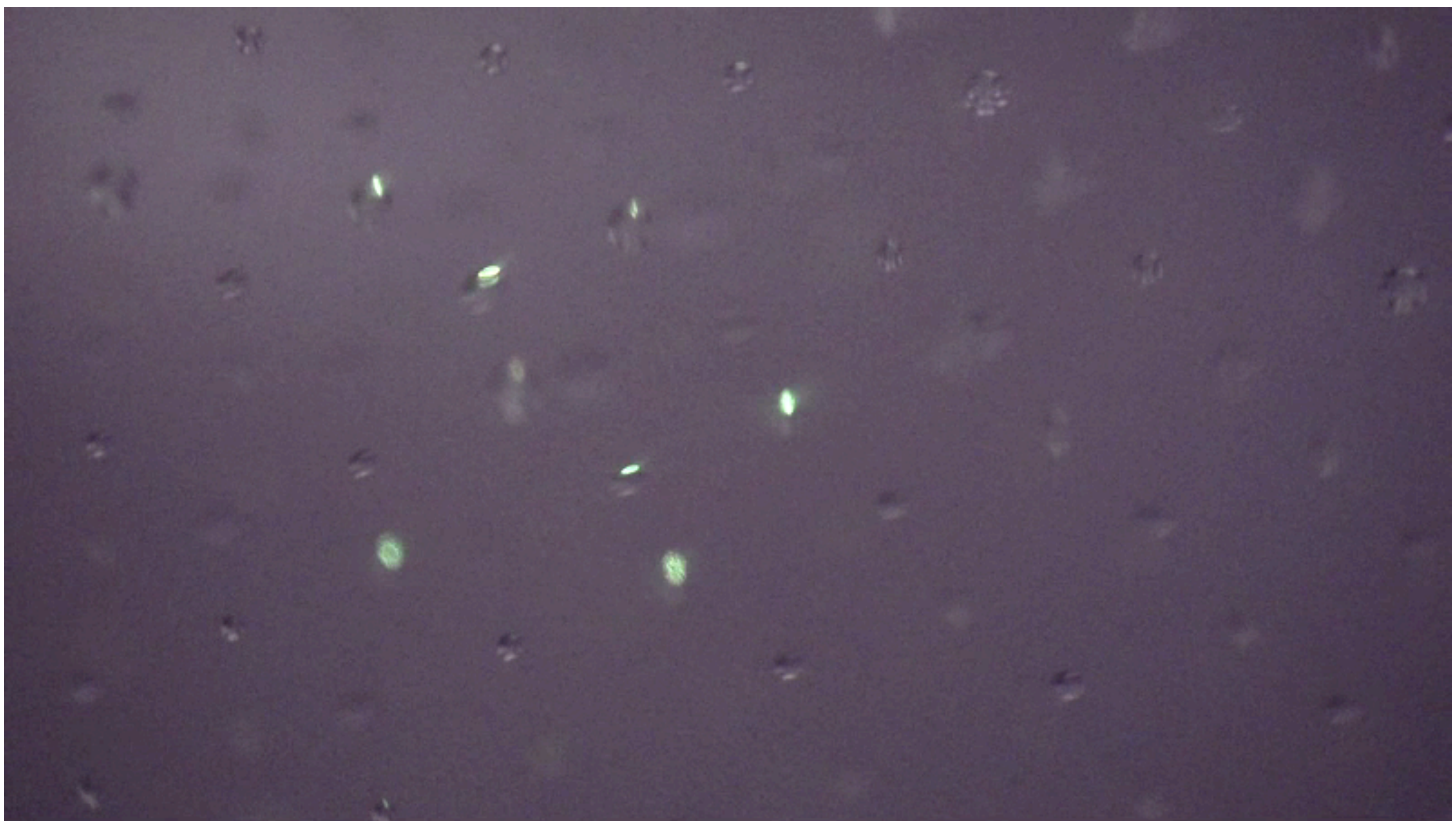
Rear-projection and optical fibers



Example: Ficon

Embodied interaction

Printed Optics



Fishkin’s metaphors

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

Fishkin’s metaphors

Analogy between the system effect of a user action to the real-world effect of similar actions

- **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)

Fishkin's metaphors

Analogy between the system effect of a user action to the real-world effect of similar actions

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

Fishkin’s metaphors

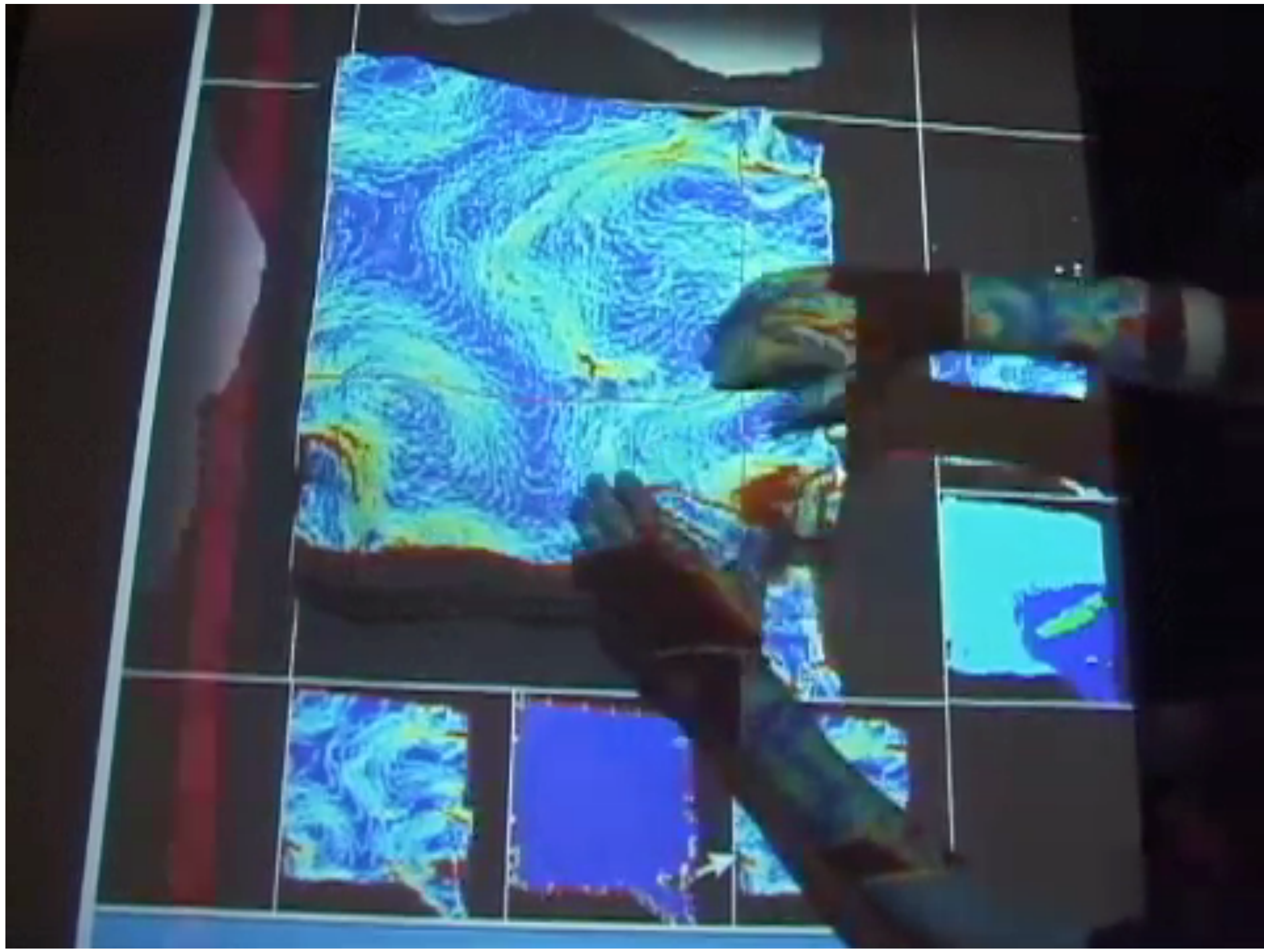
Analogy between the system effect of a user action to the real-world effect of similar actions

- **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

Fishkin’s metaphors

Analogy between the system effect of a user action to the real-world effect of similar actions

- **Full** = In user’s mind, there is no system
  - E.g., Illuminating Clay



Tangible User Interfaces
What are they good for?

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  Physical User & Physical Interface

- **Performance**:
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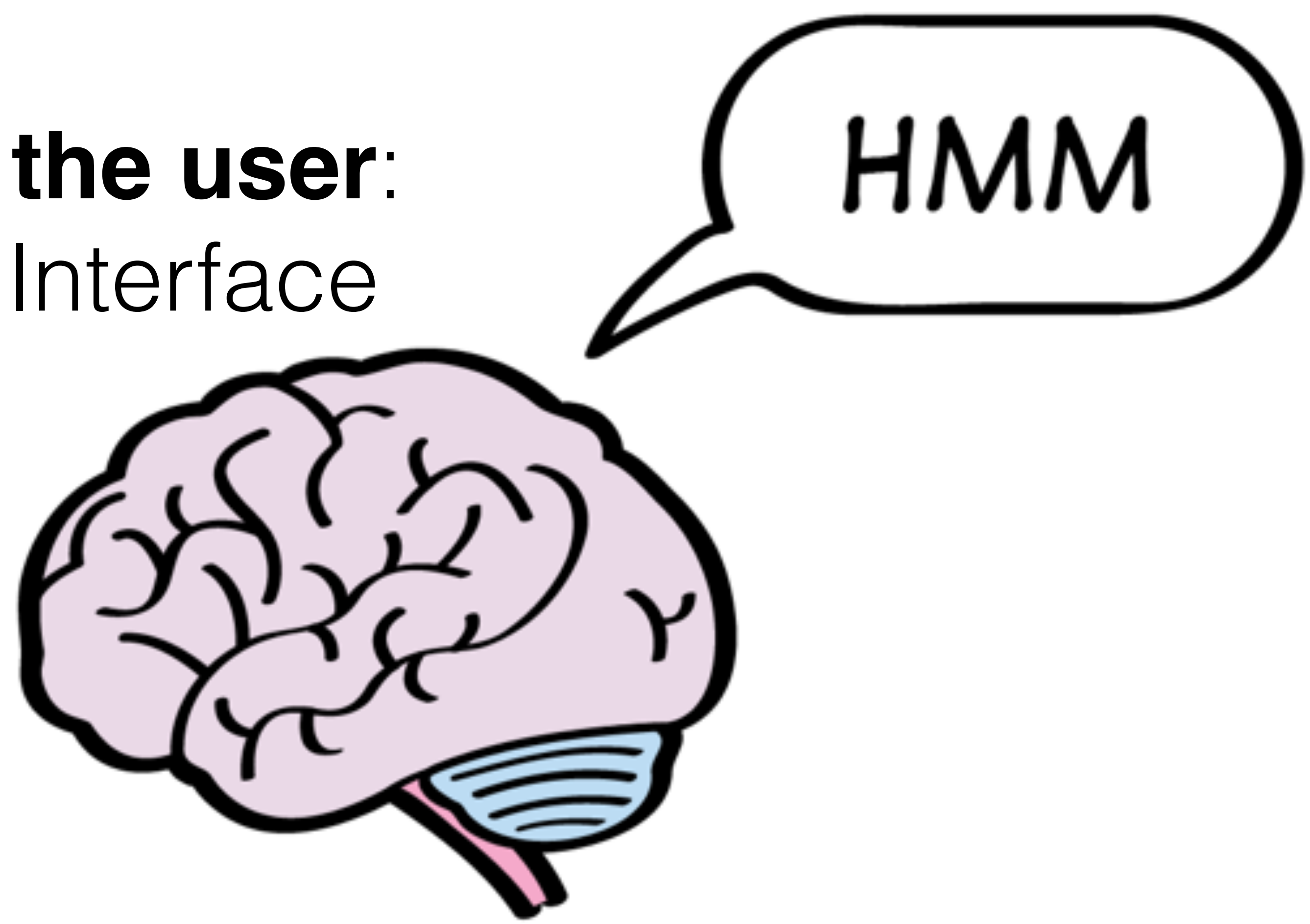


Tangible User Interfaces: What are they good for?

Several experiments demonstrated their benefits

Tangible User Interfaces: Benefit over GUI

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

Tangible User Interfaces: Benefit over GUI

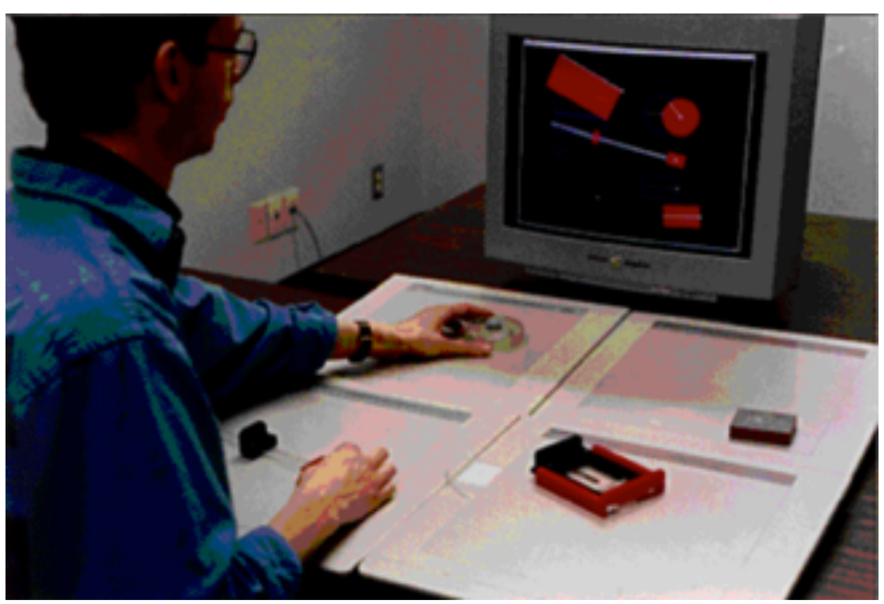
- Time-multiplexed vs. Space-multiplexed input: inter-device transaction phases

GUI	TUI
Acquire physical device | Acquire logical device | Manipulate logical device	Acquire physical device | Manipulate logical device

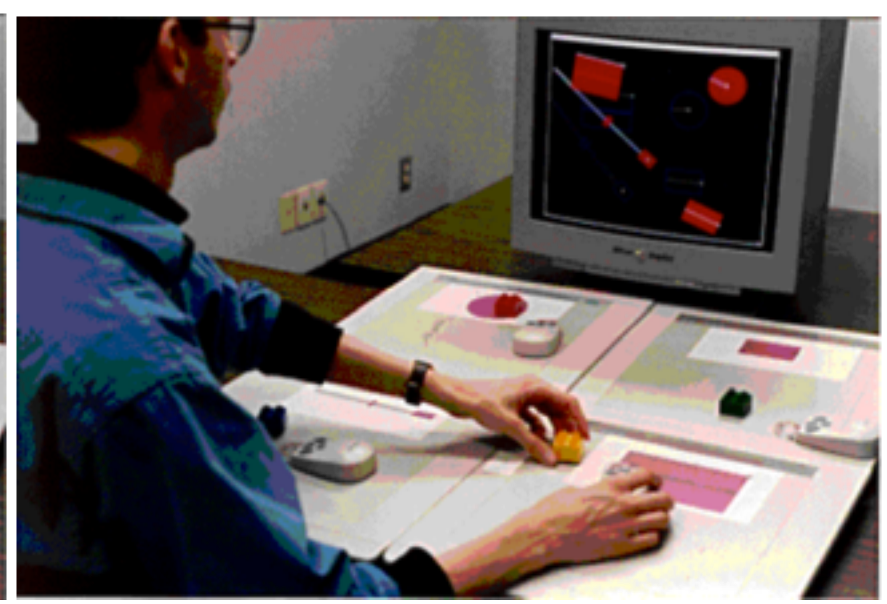
Tangible User Interfaces: Benefit over GUI

Task: continuously track four targets moving randomly on the screen (compound tasks)

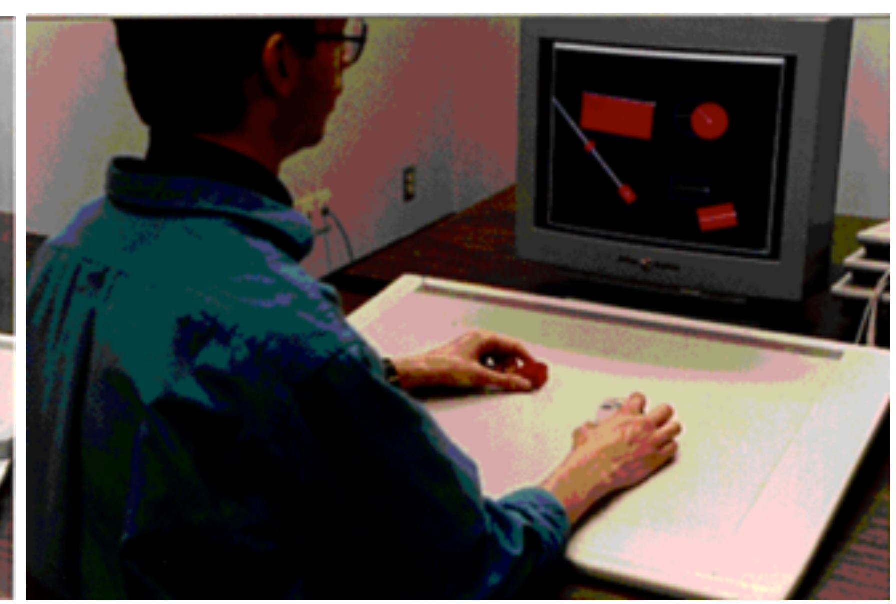
- Rotor: position and rotation
- Brick: position and rotation
- Strechable square: position, rotation and scale
- Ruler: position, rotation and scale



Space-multiplexed
Specialized



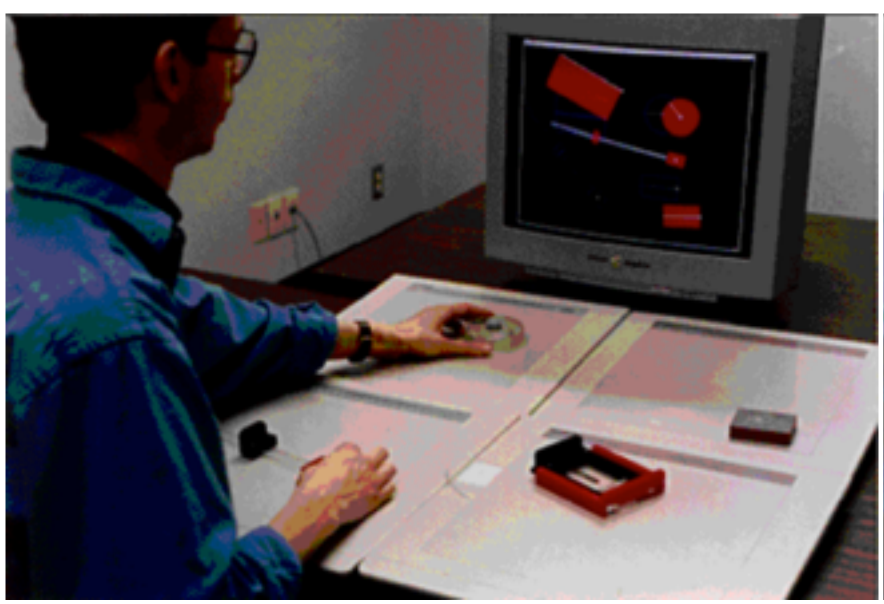
Space-multiplexed
Generic



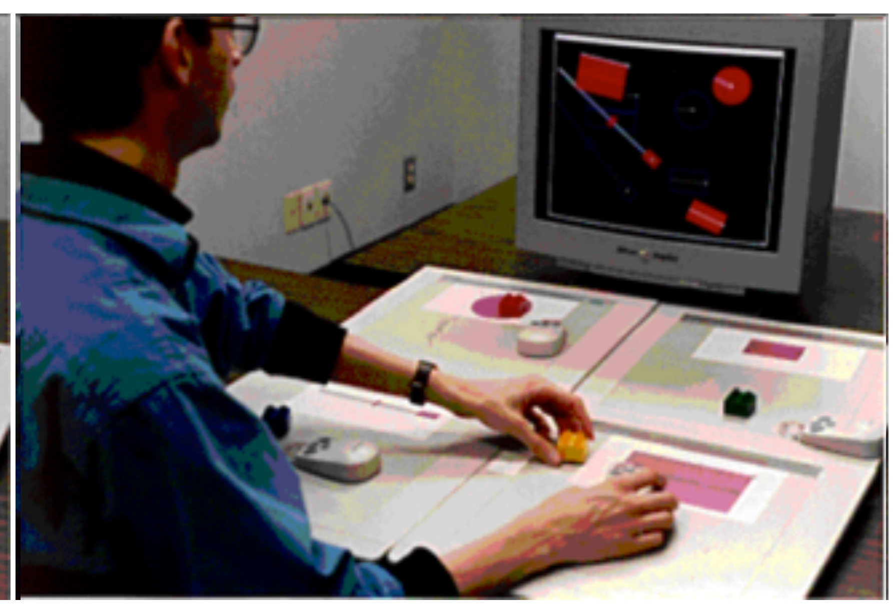
Time-multiplexed

Tangible User Interfaces: Benefit over GUI

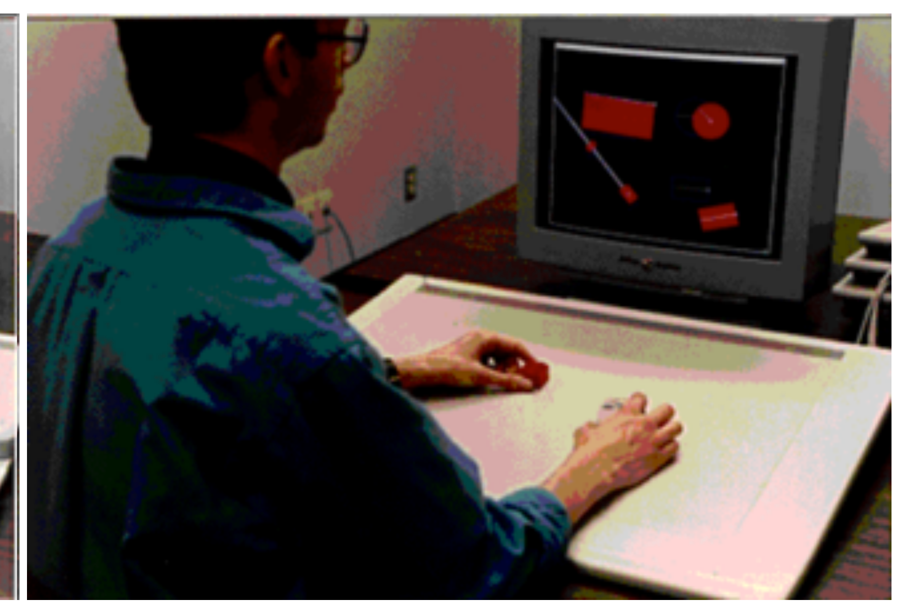
Does the **physical switching** cost more than the **logical switching** between tools?



Space-multiplexed
Specialized



Space-multiplexed
Generic

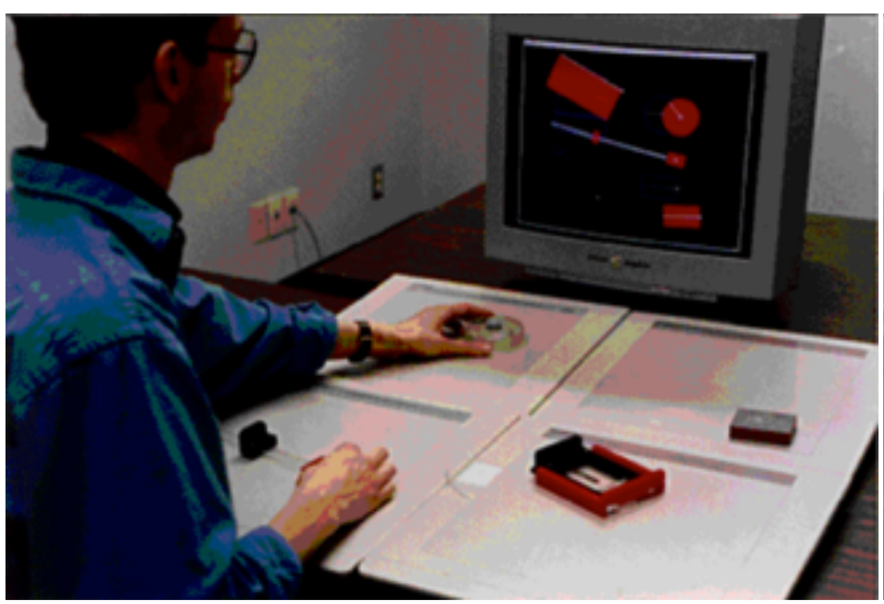


Time-multiplexed

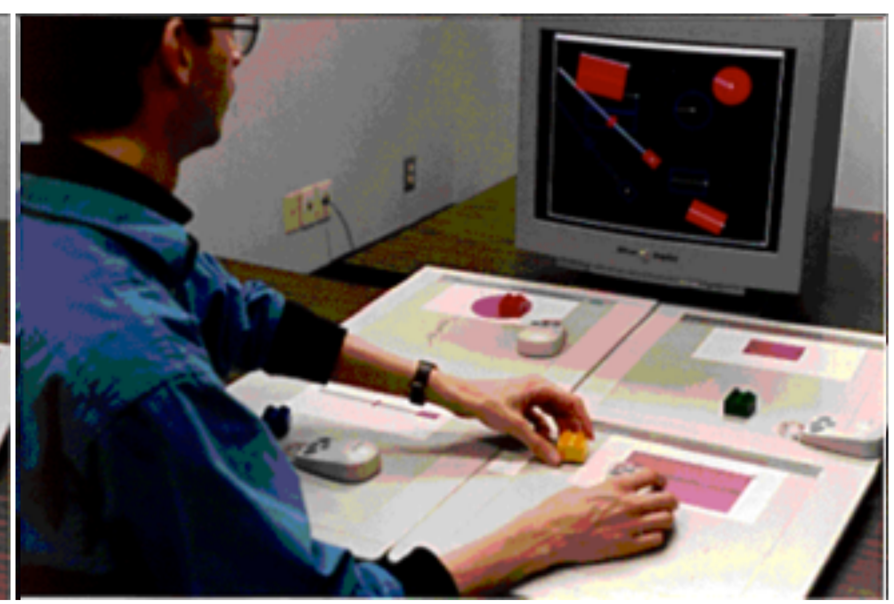
Tangible User Interfaces: Benefit over GUI

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

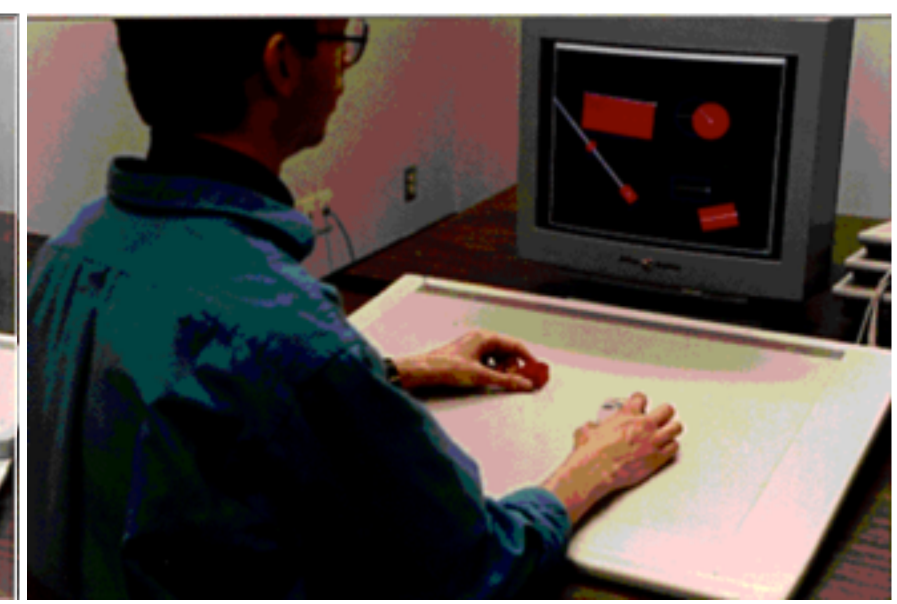
Is the **specialized** input useful?



Space-multiplexed
Specialized

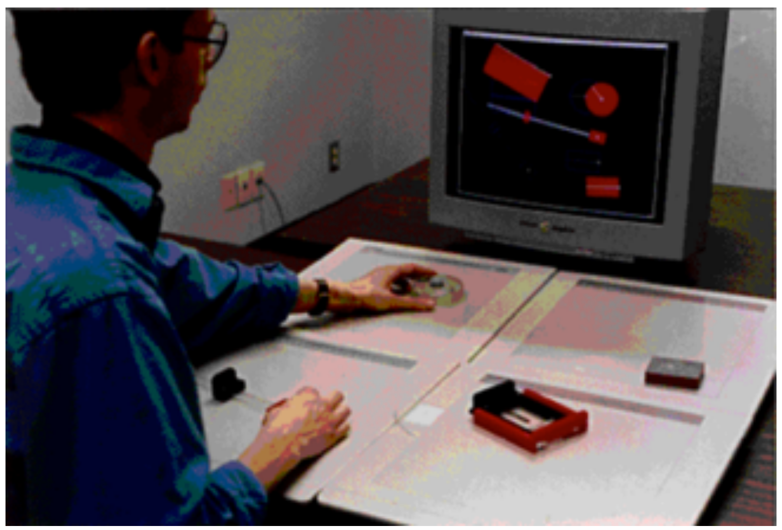


Space-multiplexed
Generic



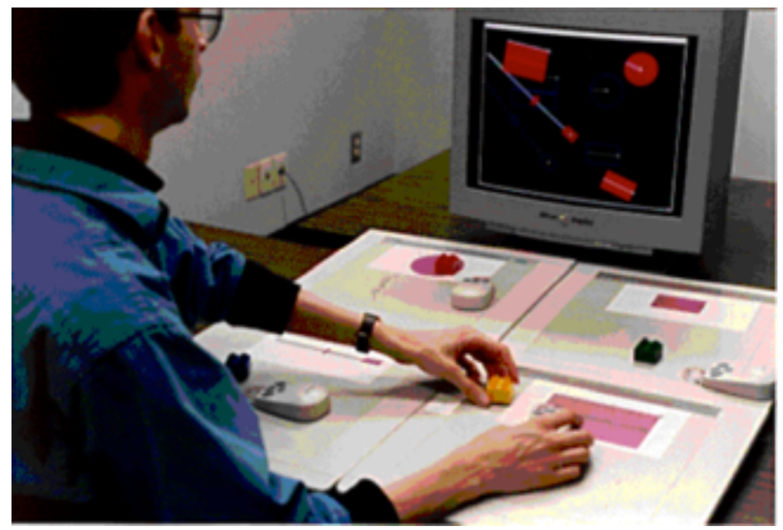
Time-multiplexed

Tangible User Interfaces: Benefit over GUI



Space-multiplexed
Specialized
performs best

>



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

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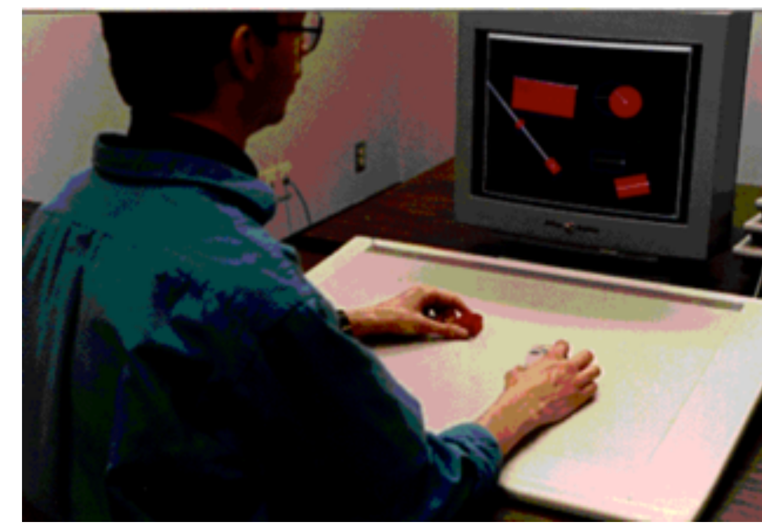
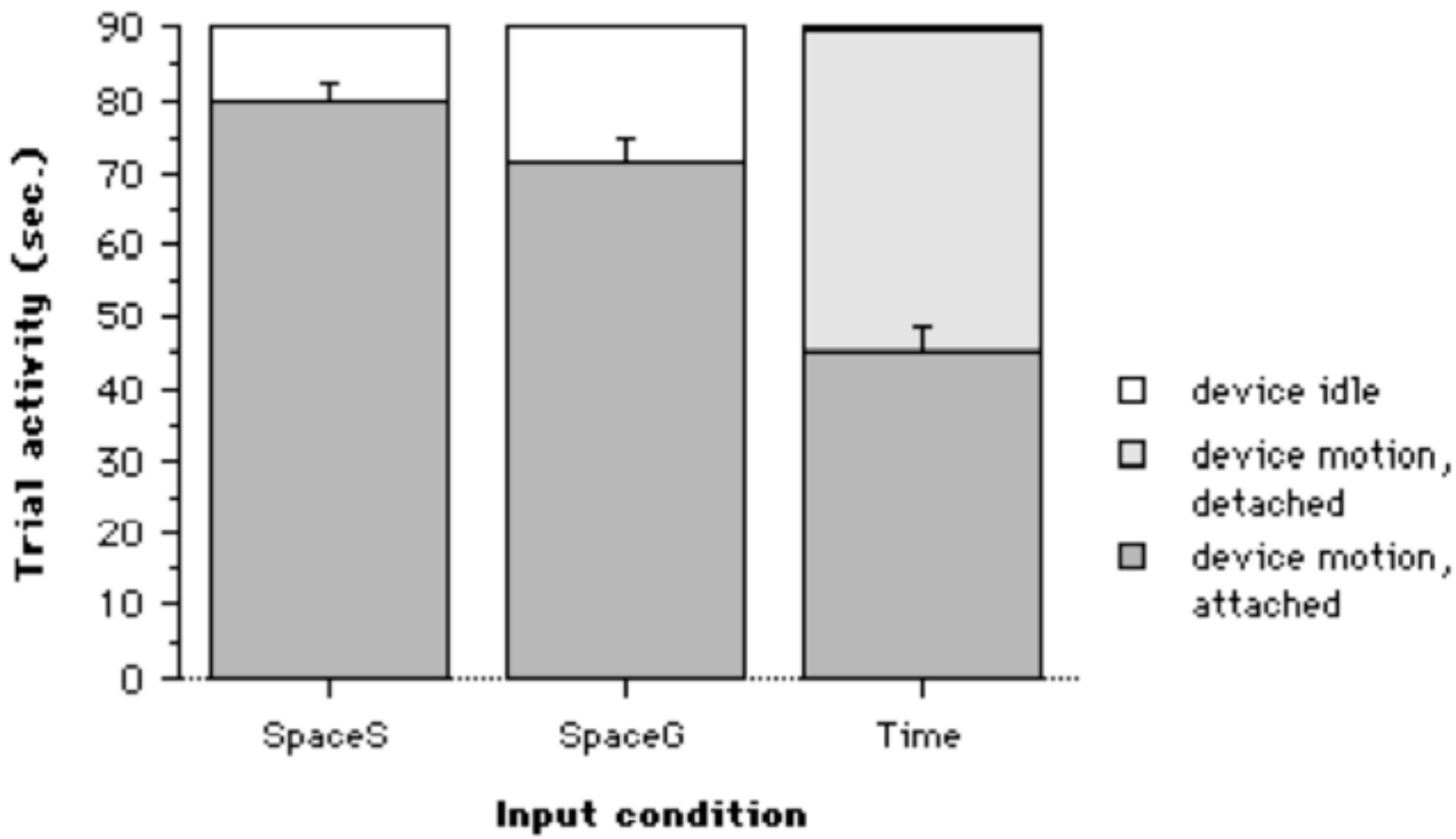


Time-multiplexed

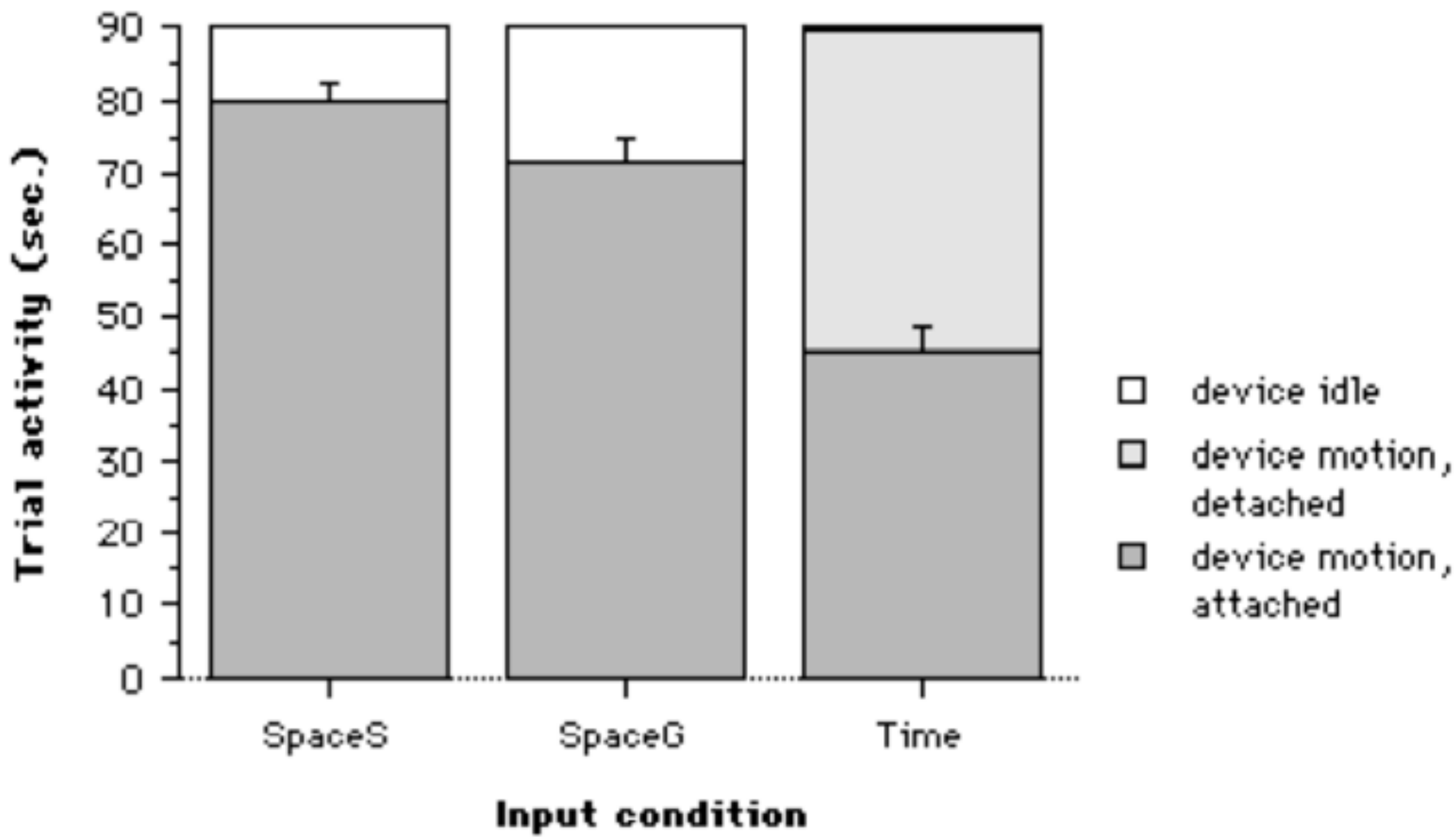
performs worst

- 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: Benefit over GUI



Tangible User Interfaces: Benefit over GUI



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

Tangible User Interfaces: Benefit over GUI

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

Tangible User Interfaces: What are they good for?

Several experiments demonstrated their benefits

Tangible User Interfaces: Benefit over multitouch

What about multitouch input?

Tangible User Interfaces: Benefit over multitouch

What about multitouch input?

also space-multiplexed

Tangible User Interfaces: Benefit over multitouch

Two experiments

Acquisition

Manipulation

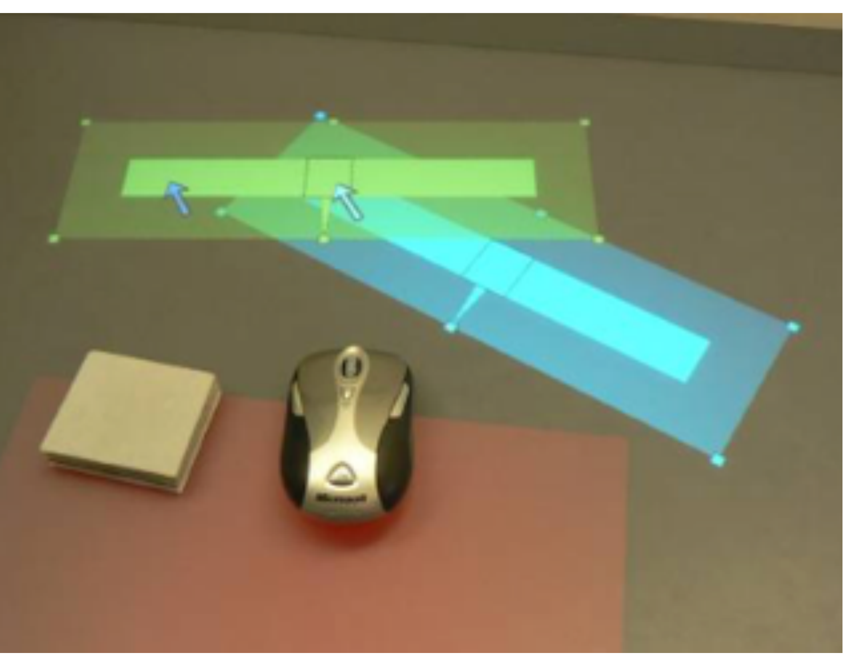
Tangible User Interfaces: Benefit over multitouch

Manipulation

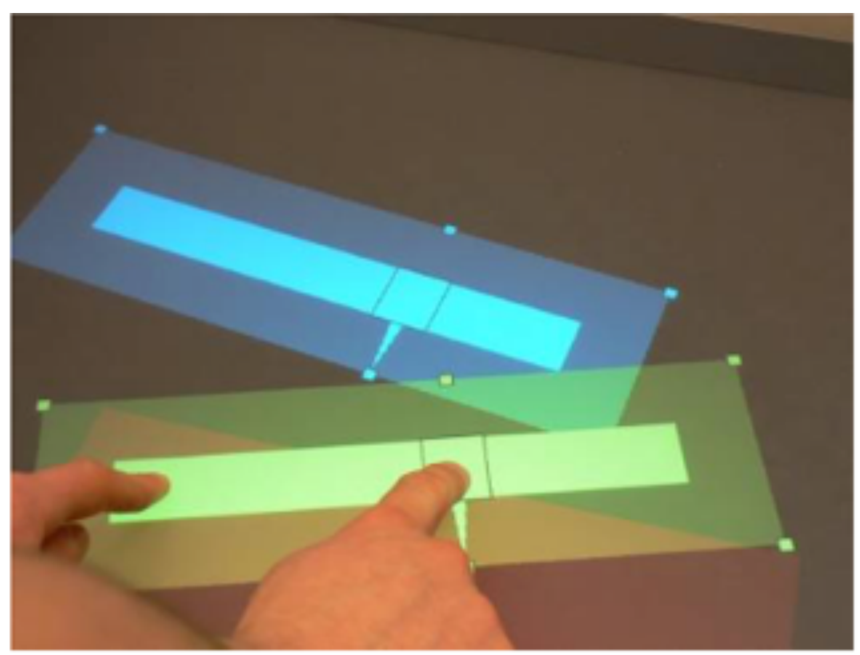
Assumes users already acquired the control widget

Tangible User Interfaces: Benefit over multitouch

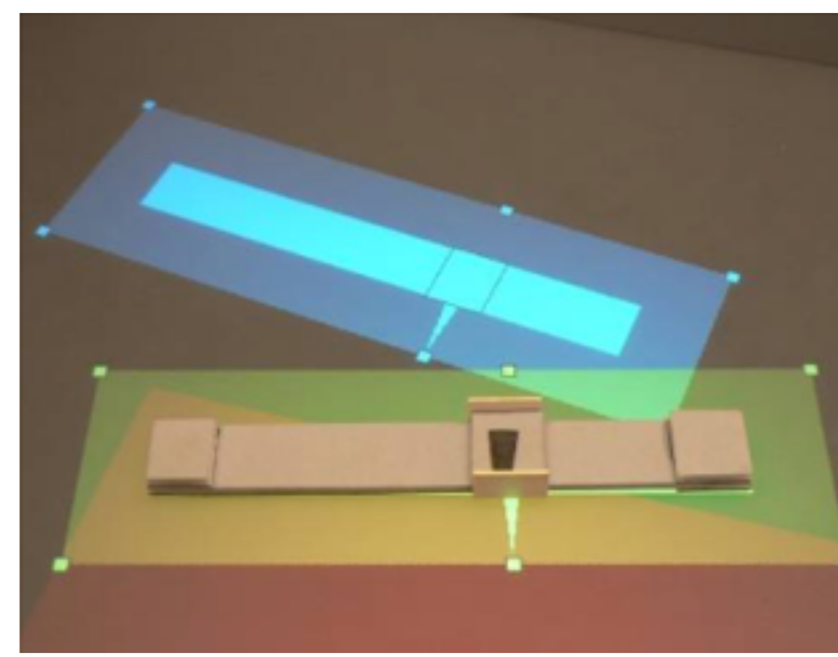
Task: match position+orientation+cursor of blue object
manipulating yellow object
as quickly as possible



Mouse+Puck



Multitouch



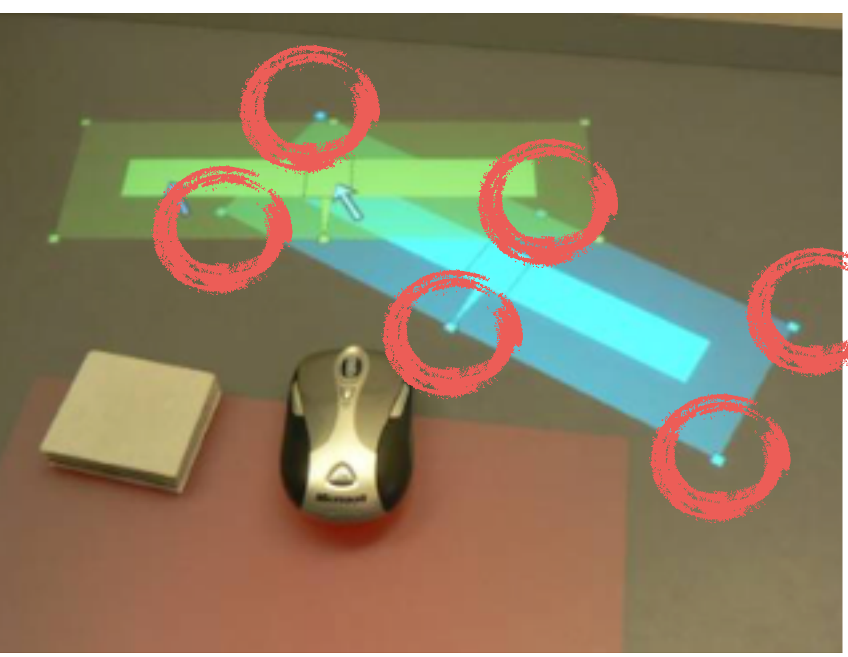
Tangible

(all conditions sensed through multitouch table)

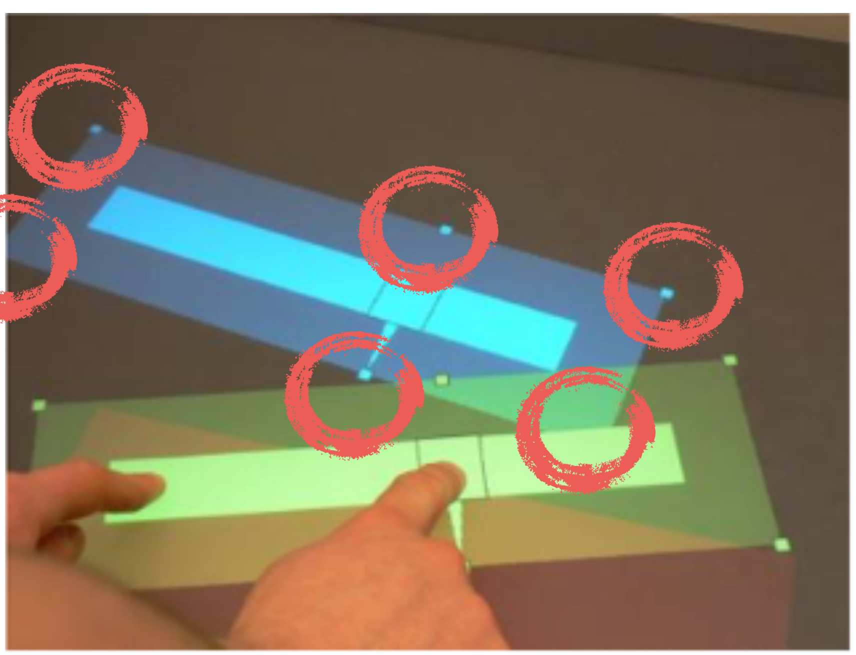
Tangible User Interfaces: Benefit over multitouch

Task: match position+orientation+cursor of blue object
manipulating yellow object
as quickly as possible

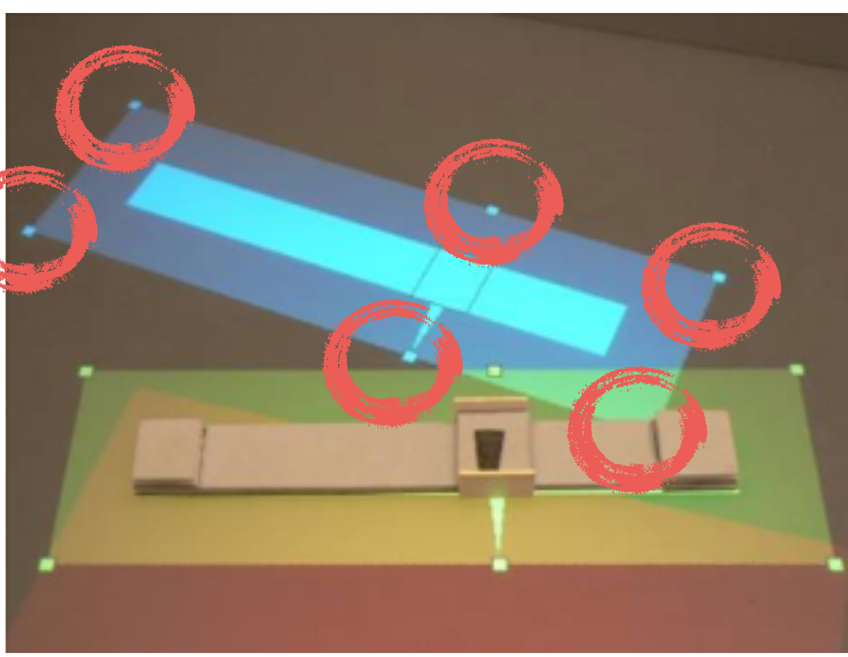
±5px



Mouse+Puck



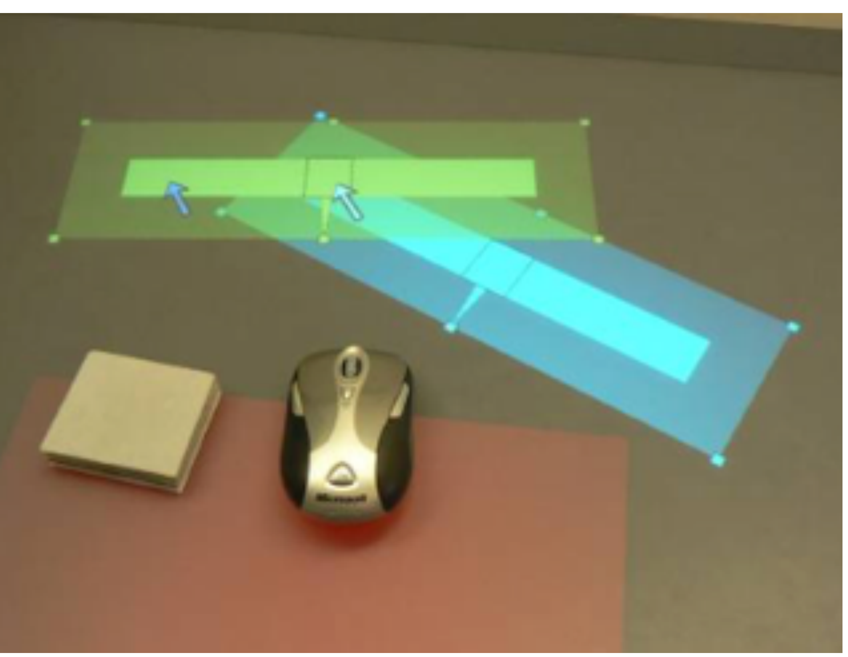
Multitouch



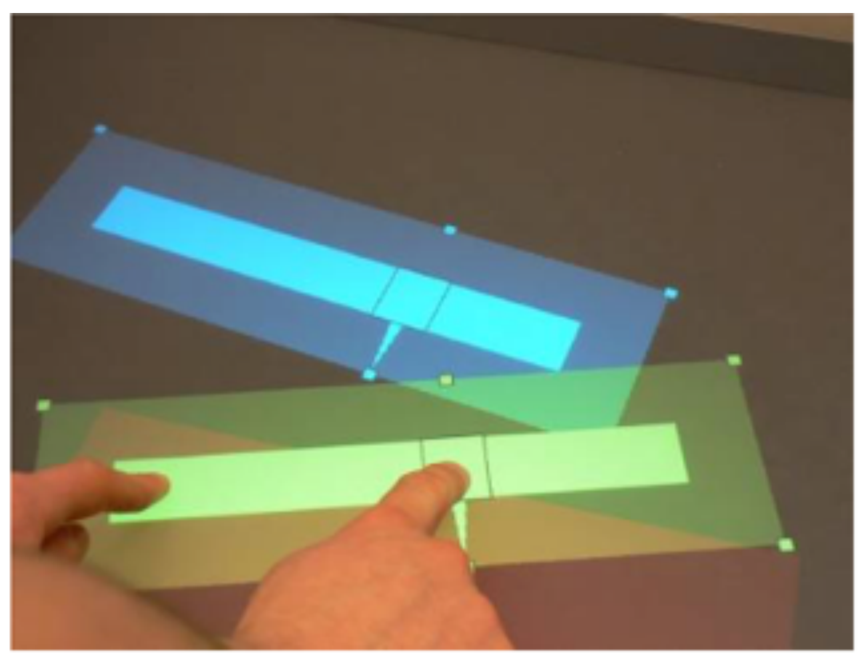
Tangible

Tangible User Interfaces: Benefit over multitouch

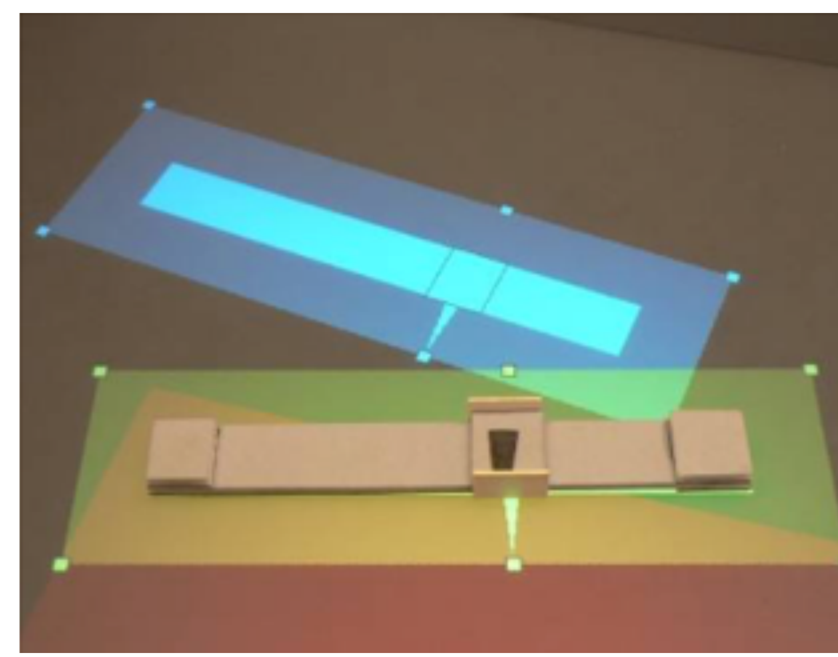
Measures: Time to complete matching task
Subjective comfort
Subjective ease of use



Mouse+Puck

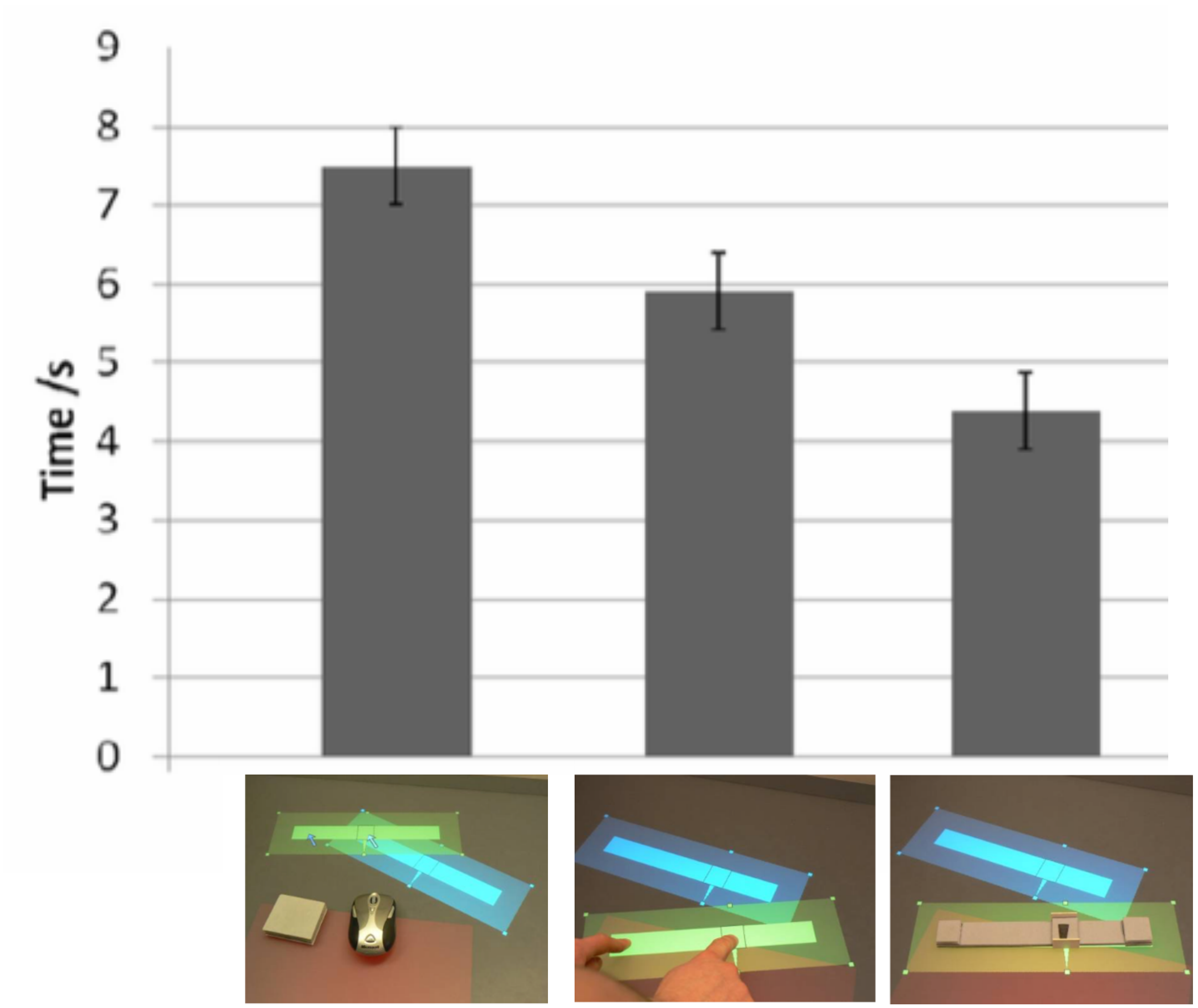


Multitouch



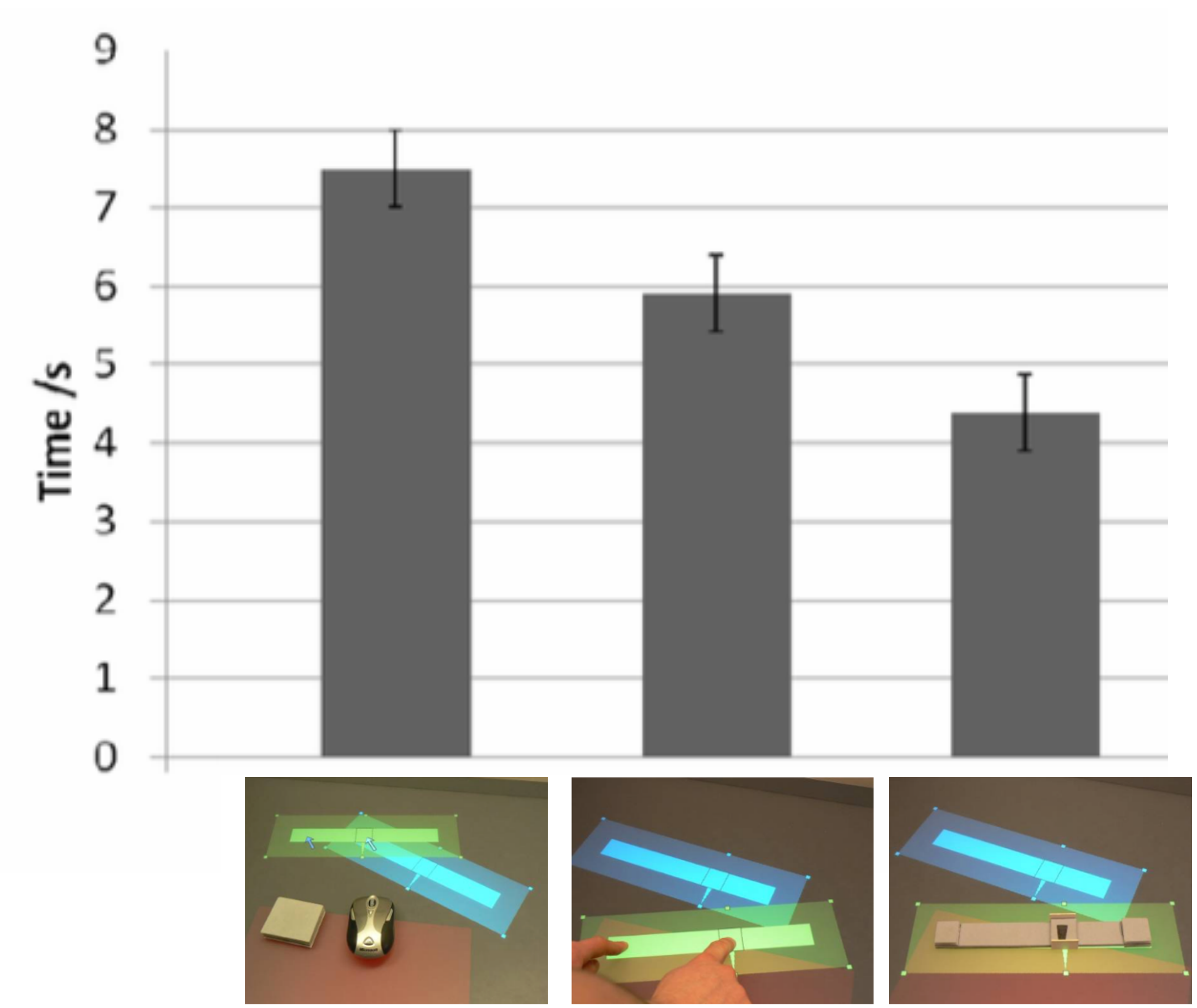
Tangible

Tangible User Interfaces: Benefit over multitouch



Mouse+Puck Multitouch Tangible

Tangible User Interfaces: Benefit over multitouch



Mouse+Puck Multitouch Tangible

+ Little difference in comfort and ease of use

A participant:
« better degree of control with tangibles, especially when rotating »

Tangible User Interfaces: Benefit over multitouch

Manipulation

Tangible User Interfaces: Benefit over multitouch

Two experiments

Acquisition

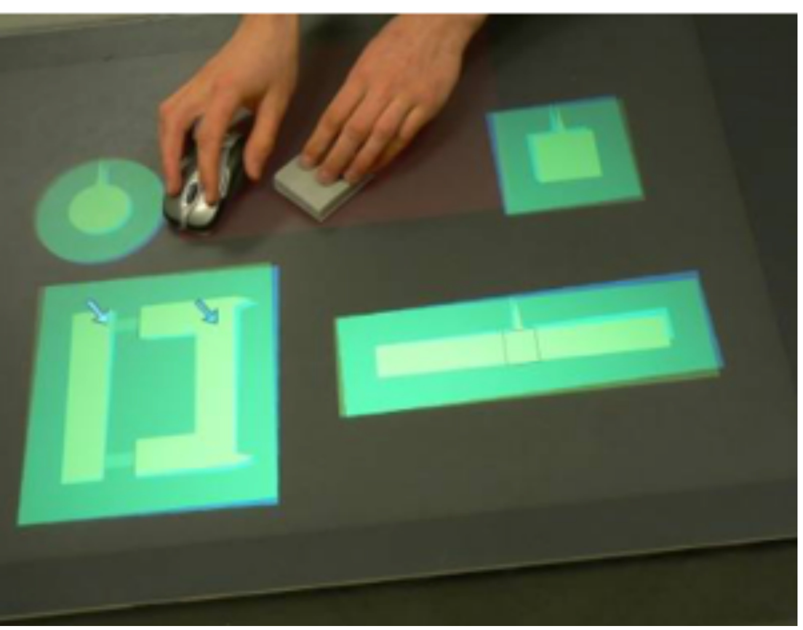
Manipulation

Tangible User Interfaces: Benefit over multitouch

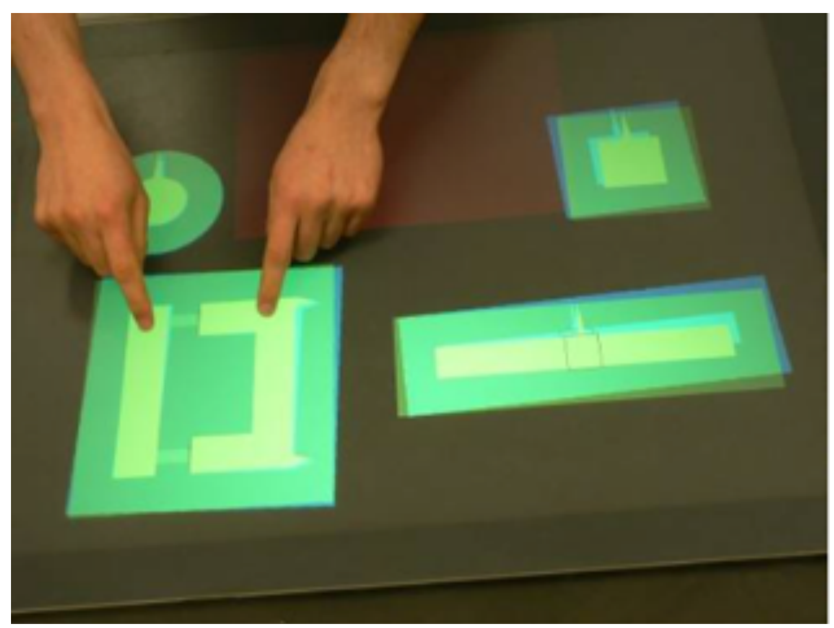
Acquisition

Tangible User Interfaces: Benefit over multitouch

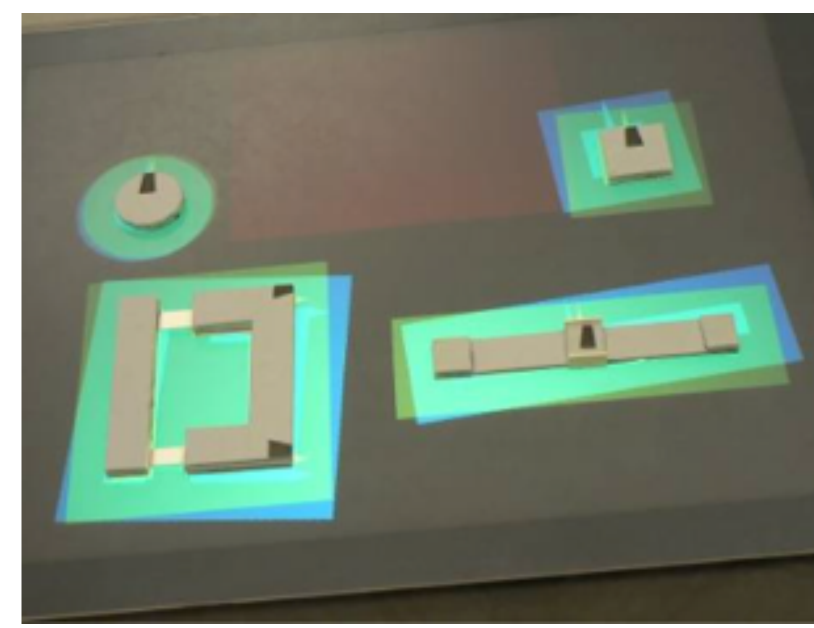
Task: match position+orientation+cursor of blue objects manipulating yellow objects at all times



Mouse+Puck



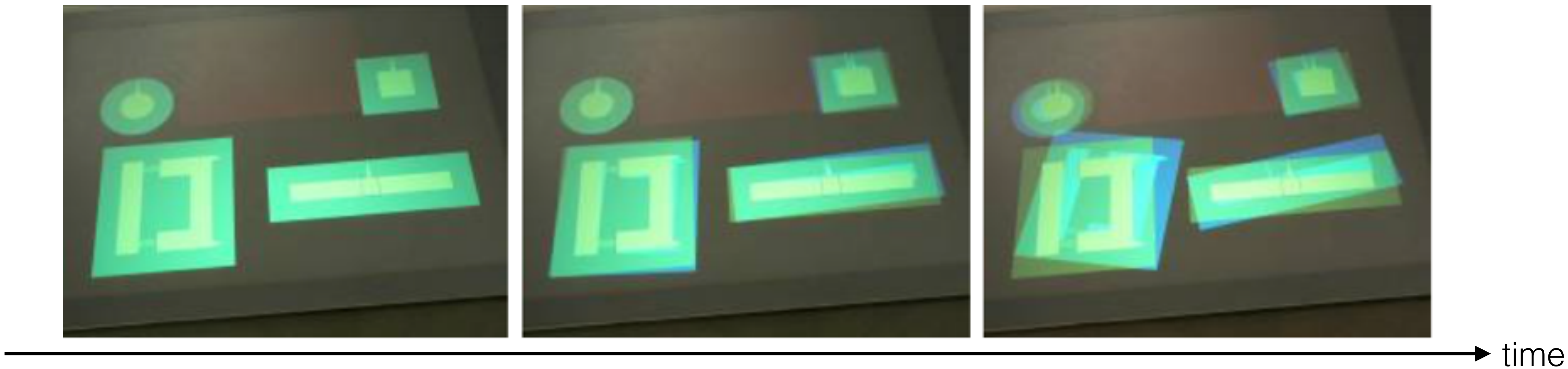
Multitouch



Tangible

(all conditions sensed through multitouch table)

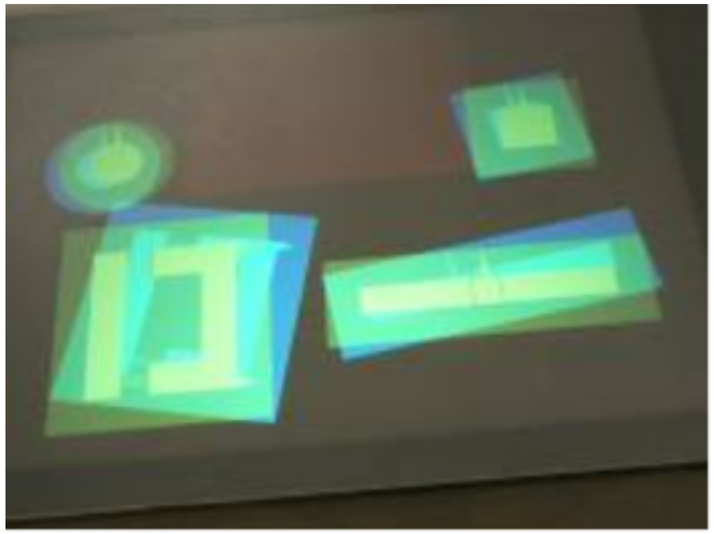
Tangible User Interfaces: Benefit over multitouch



Task: match position+orientation+cursor of blue objects
manipulating yellow objects
at all times

⇒ move between widgets ⇒ many (re)acquisitions

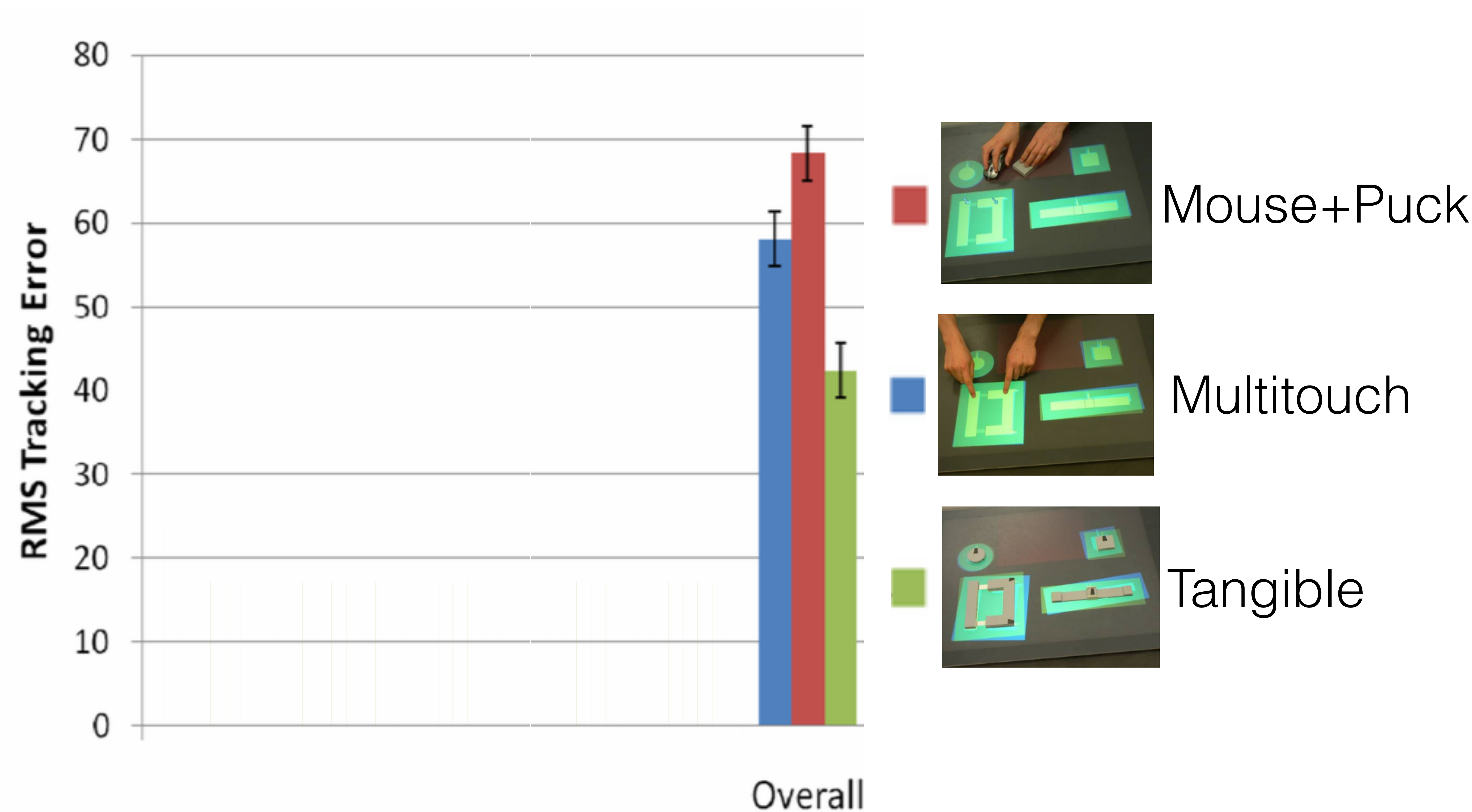
Tangible User Interfaces: Benefit over multitouch



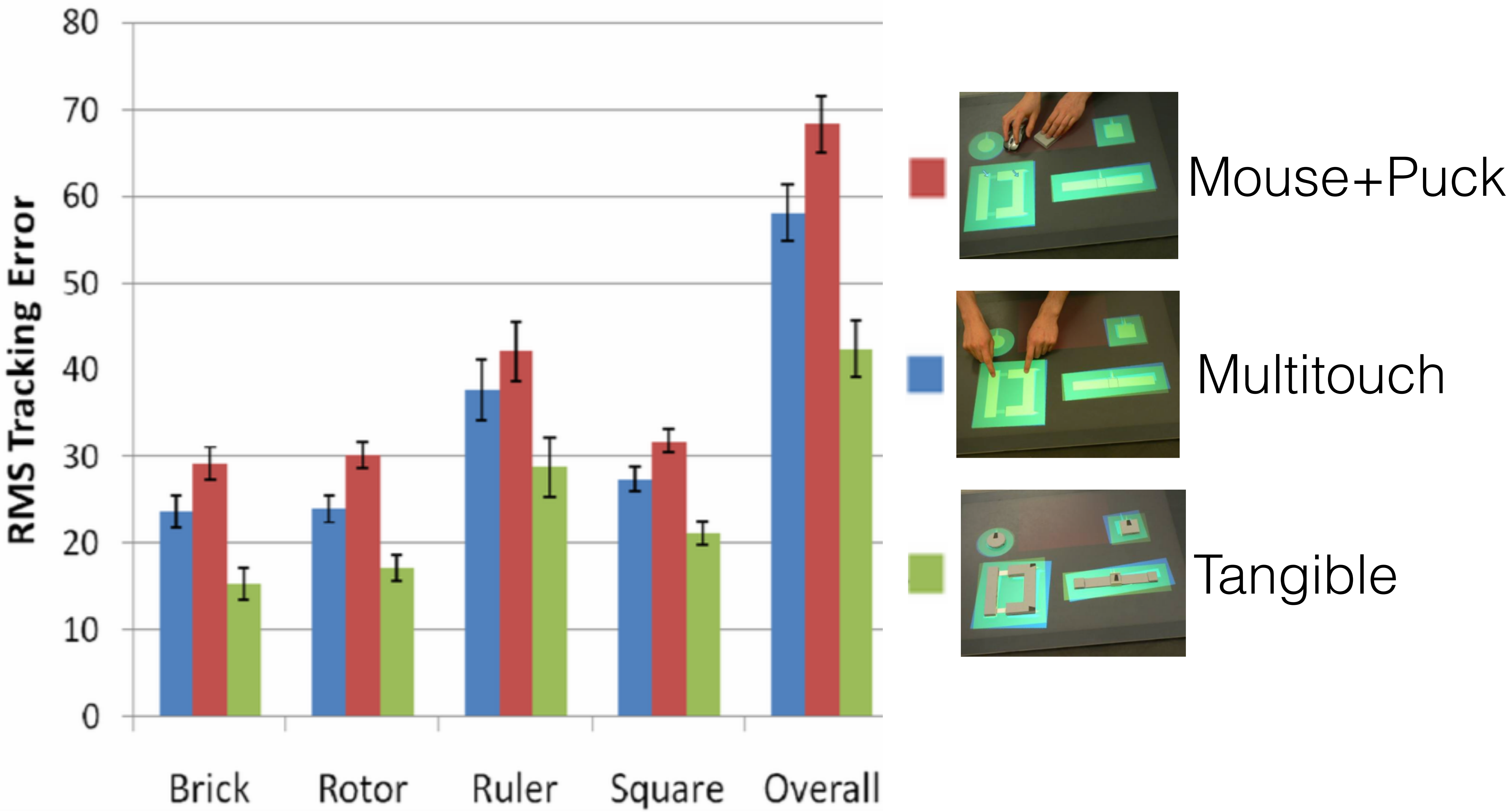
Measures: root-mean-square errors
of all dimensions
(position, orientation and scale or cursor position if applicable)
of all devices

+ subjective preference, confort and ease of use

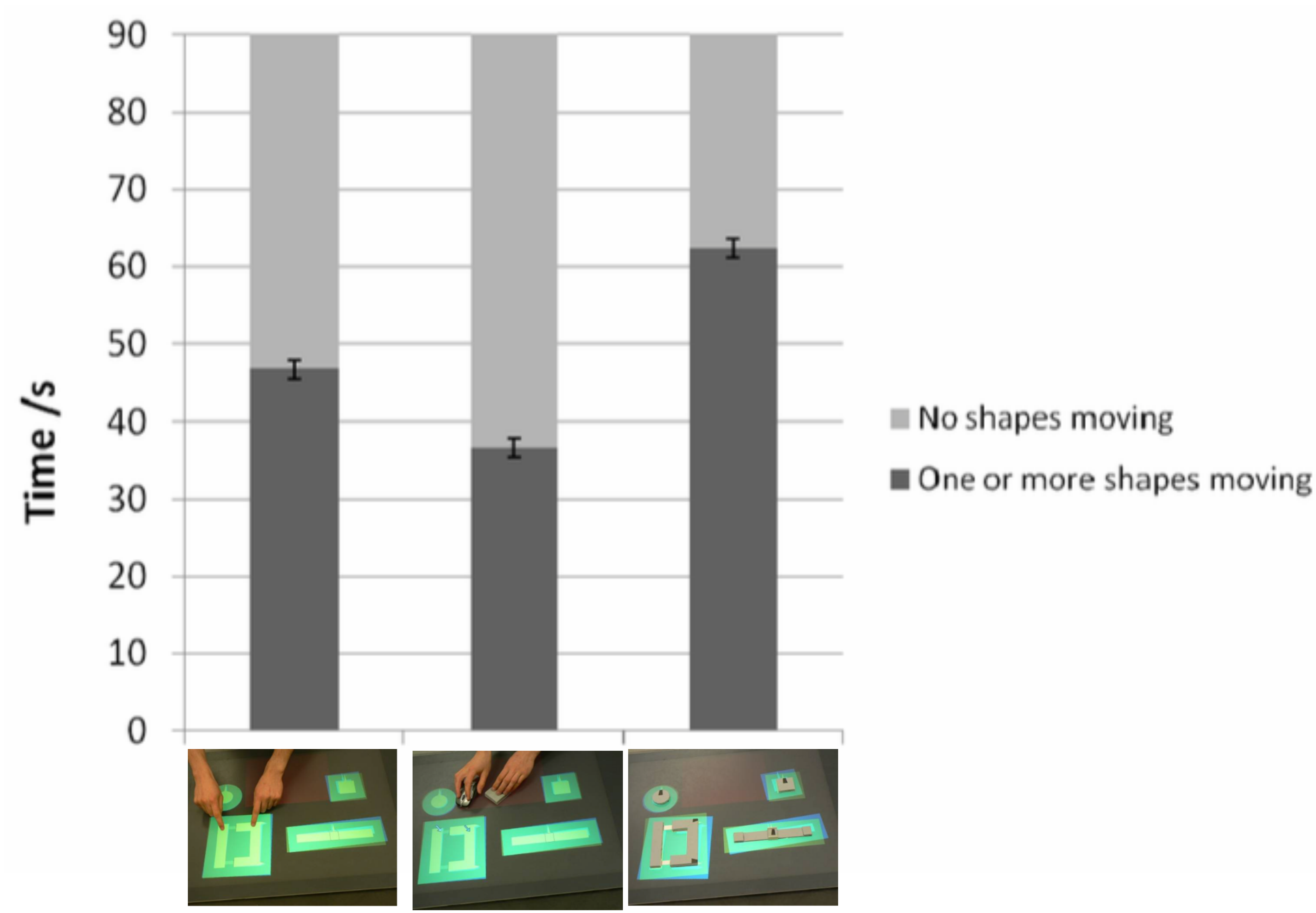
Tangible User Interfaces: Benefit over multitouch



Tangible User Interfaces: Benefit over multitouch

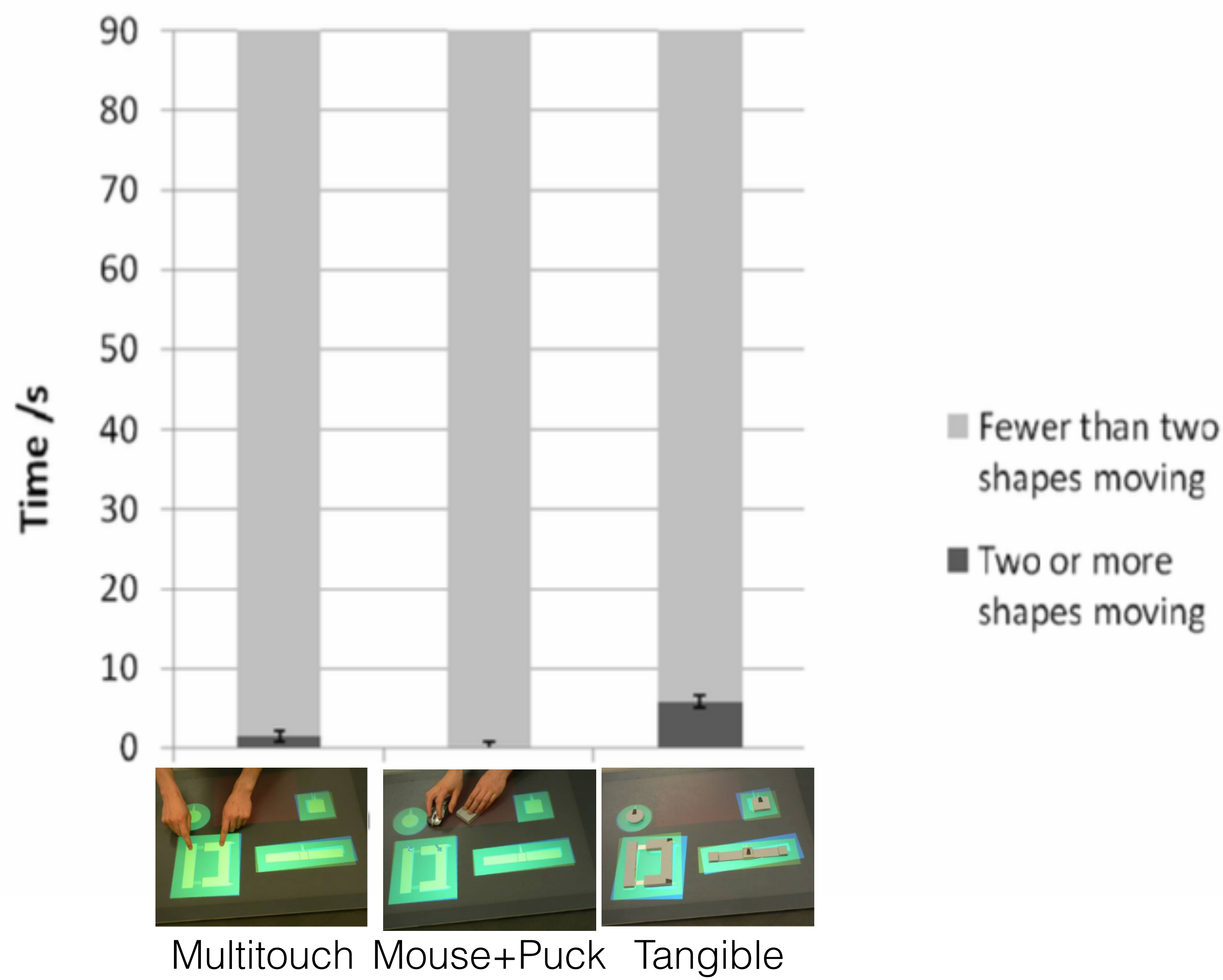


Tangible User Interfaces: Benefit over multitouch

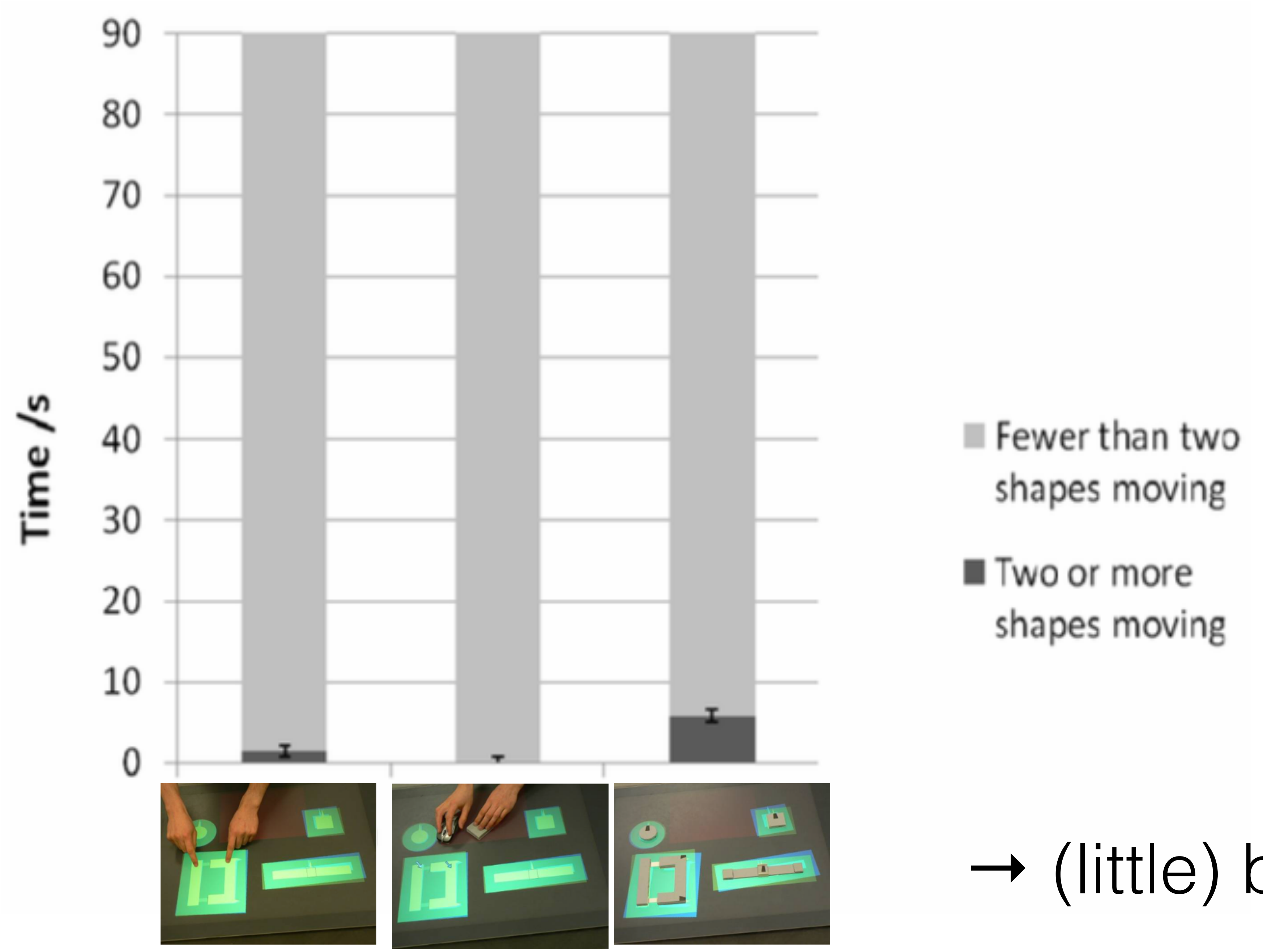


Multitouch Mouse+Puck Tangible

Tangible User Interfaces: Benefit over multitouch



Tangible User Interfaces: Benefit over multitouch

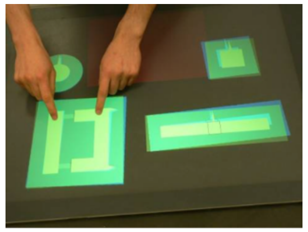


Multitouch Mouse+Puck Tangible

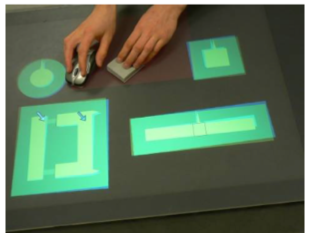
→ (little) bimanualism

Tangible User Interfaces: Benefit over multitouch

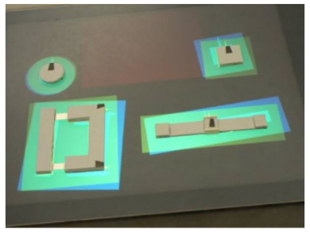
+ Little difference in preference, comfort and ease of use



Multitouch

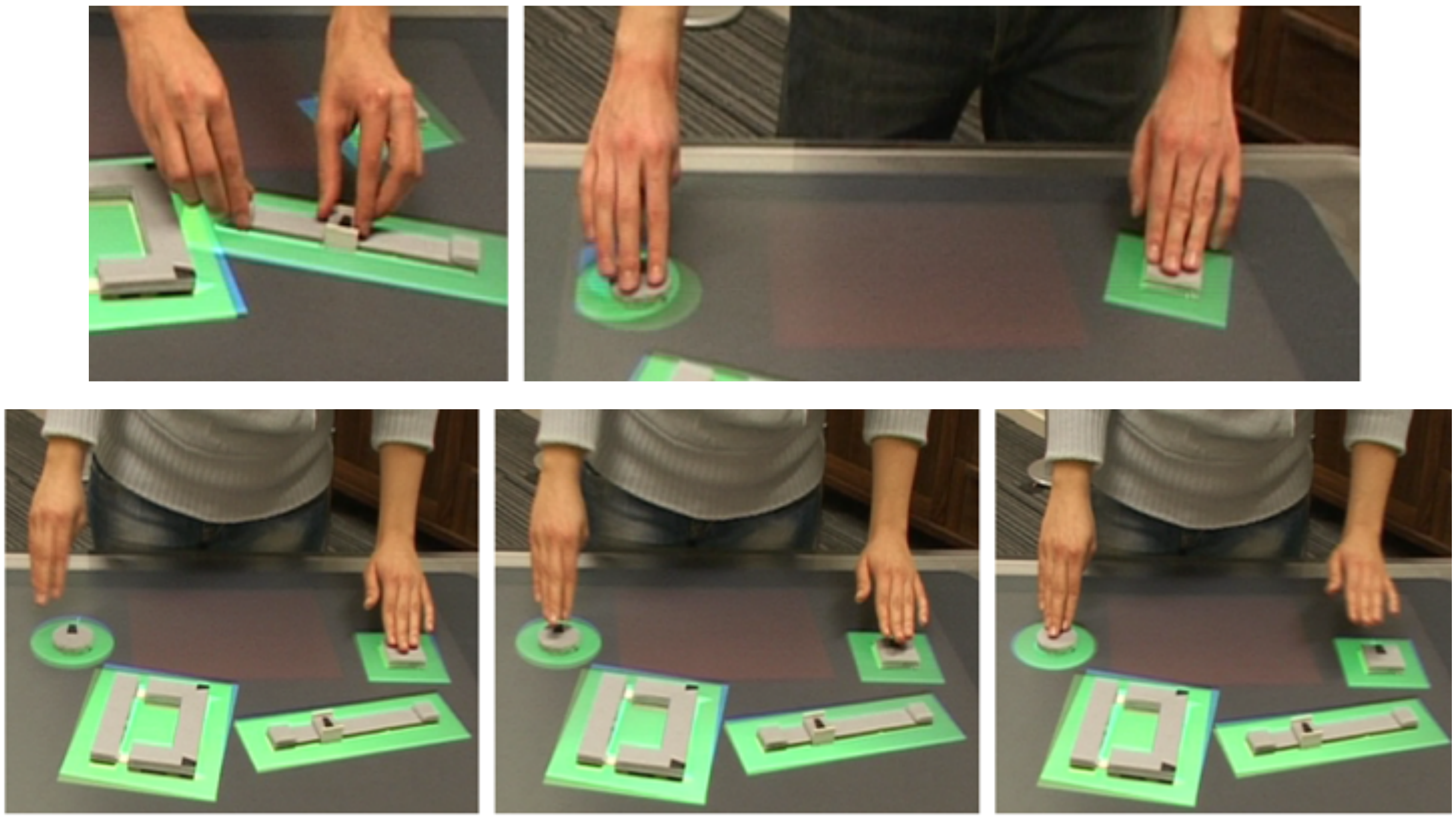


Mouse+Puck



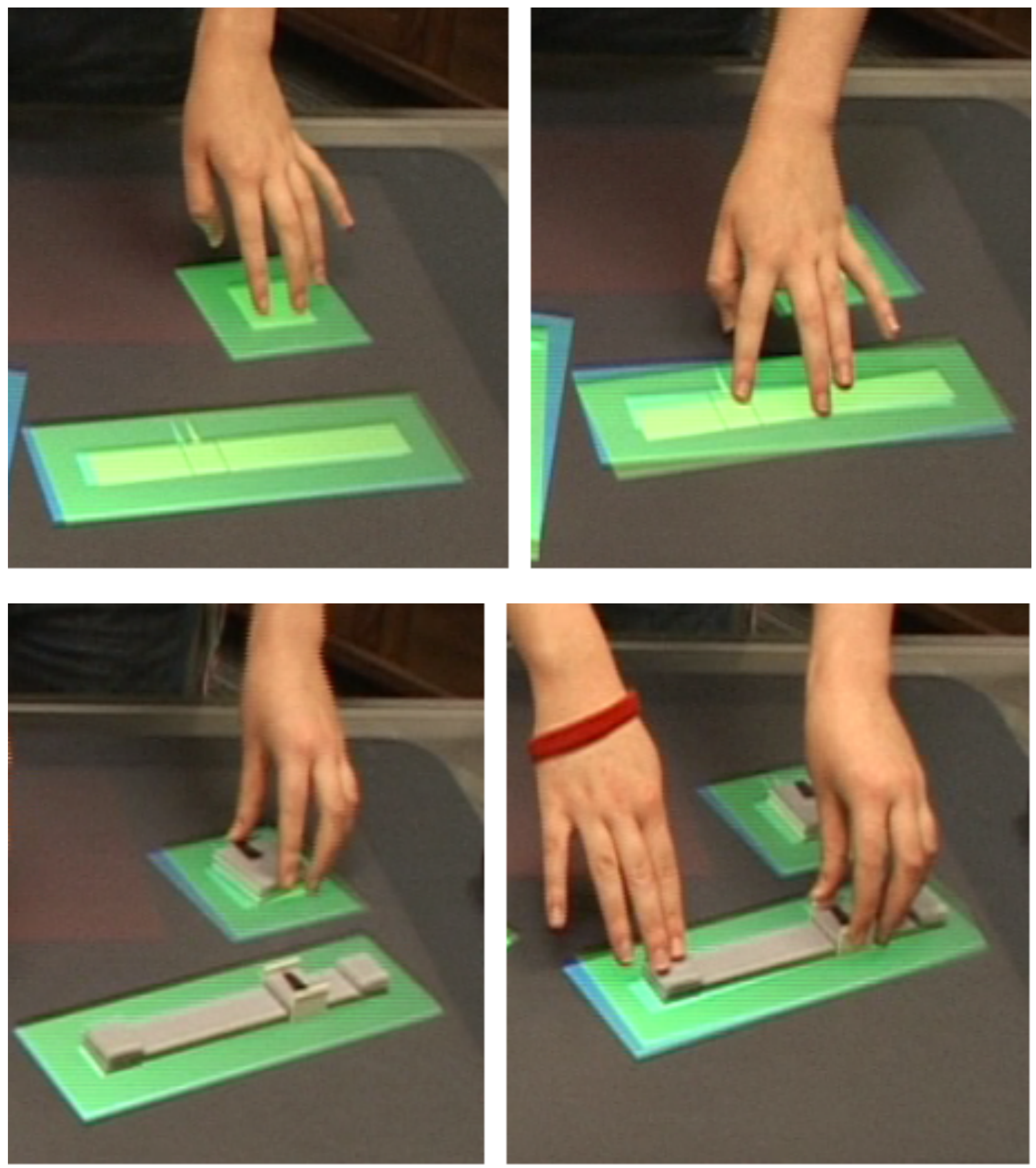
Tangible

Tangible User Interfaces: Benefit over multitouch



Same pattern for multitouch and tangible

Tangible User Interfaces: Benefit over multitouch



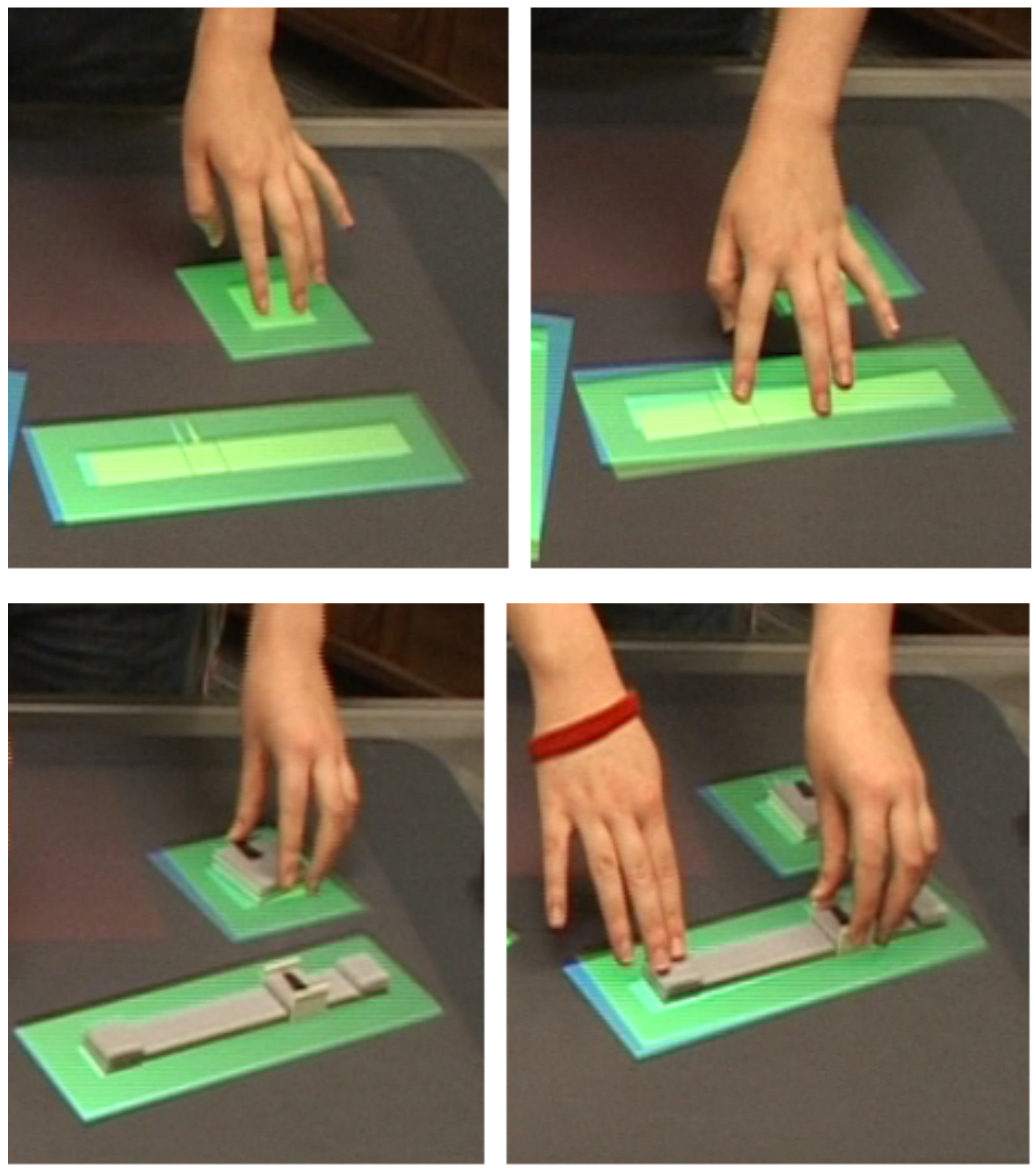
multitouch

≠

tangible

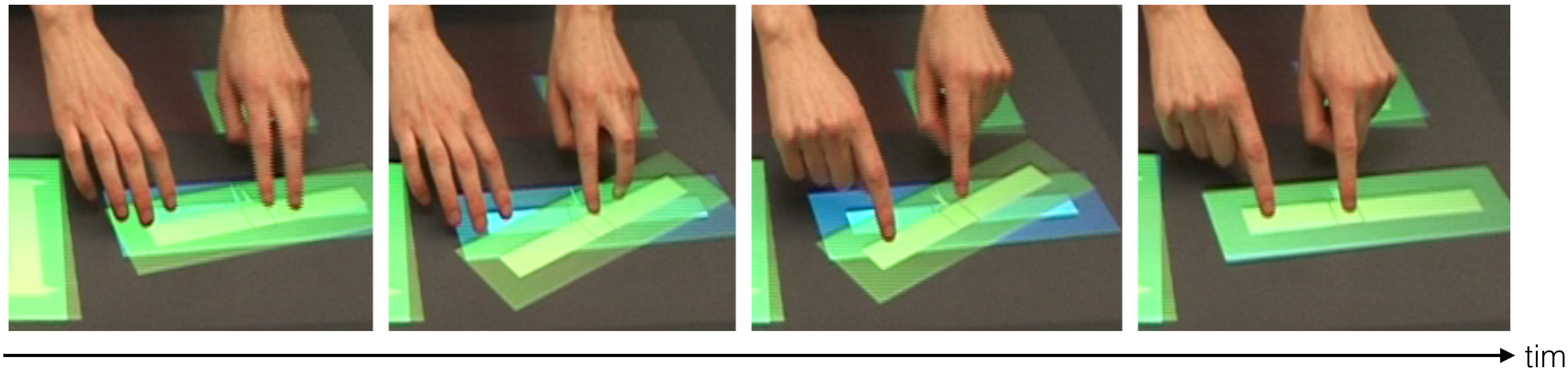
Tangible User Interfaces: Benefit over multitouch

number of contact points



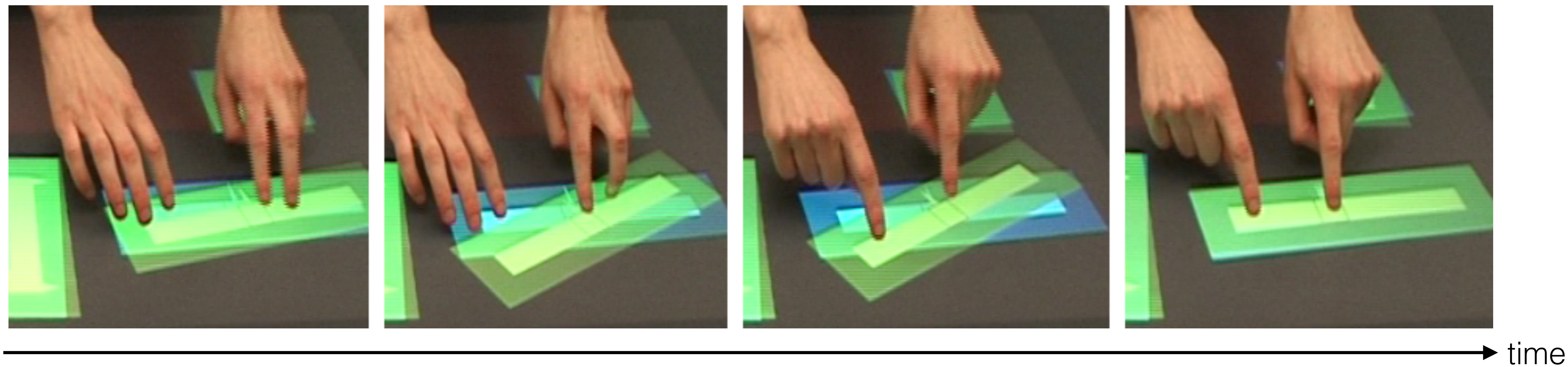
multitouch
≠
tangible

Tangible User Interfaces: Benefit over multitouch



multitouch:
number of contact points

Tangible User Interfaces: Benefit over multitouch



multitouch:
number of contact points decrease ⇒ more accurate

tangible:
number of contact points increase ⇒ more accurate

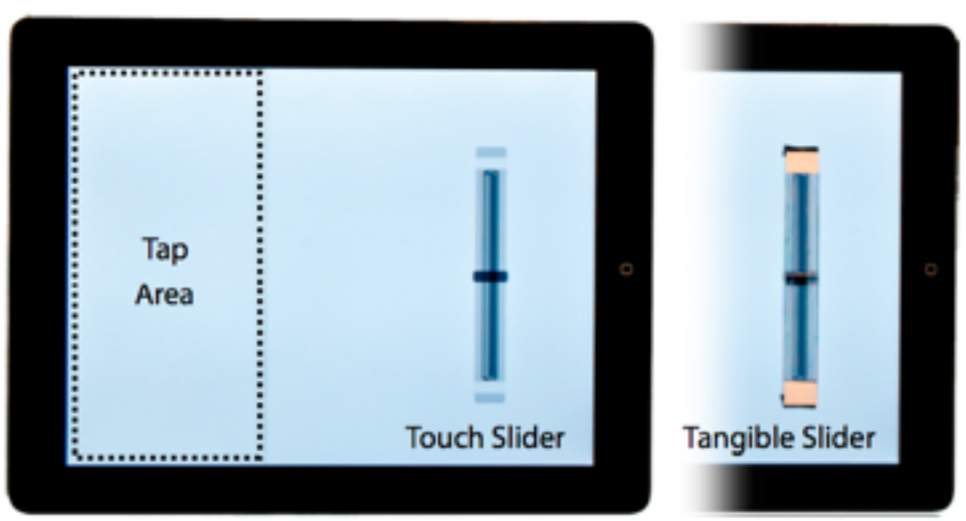
+ greater variability within and between participants

Tangible User Interfaces: What are they good for?

Several experiments demonstrated their benefits

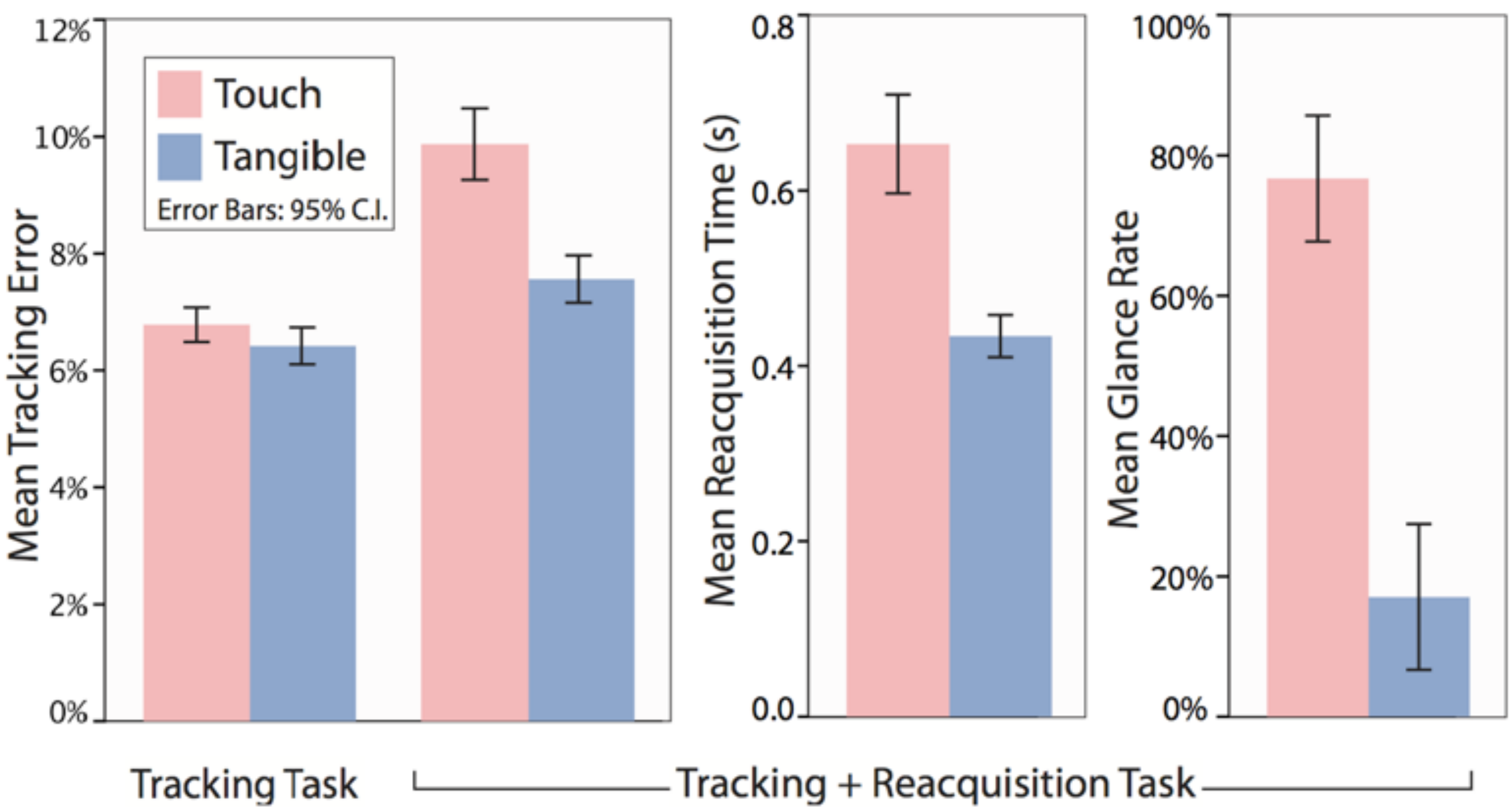
Tangible User Interfaces: Benefit for distant interaction

- Techniques: Touch vs. Tangible slider
- Tasks: Tracking vs. Tracking + additional tapping



Tangible User Interfaces: Benefit for distant interaction

- Comparing touch and tangible interaction

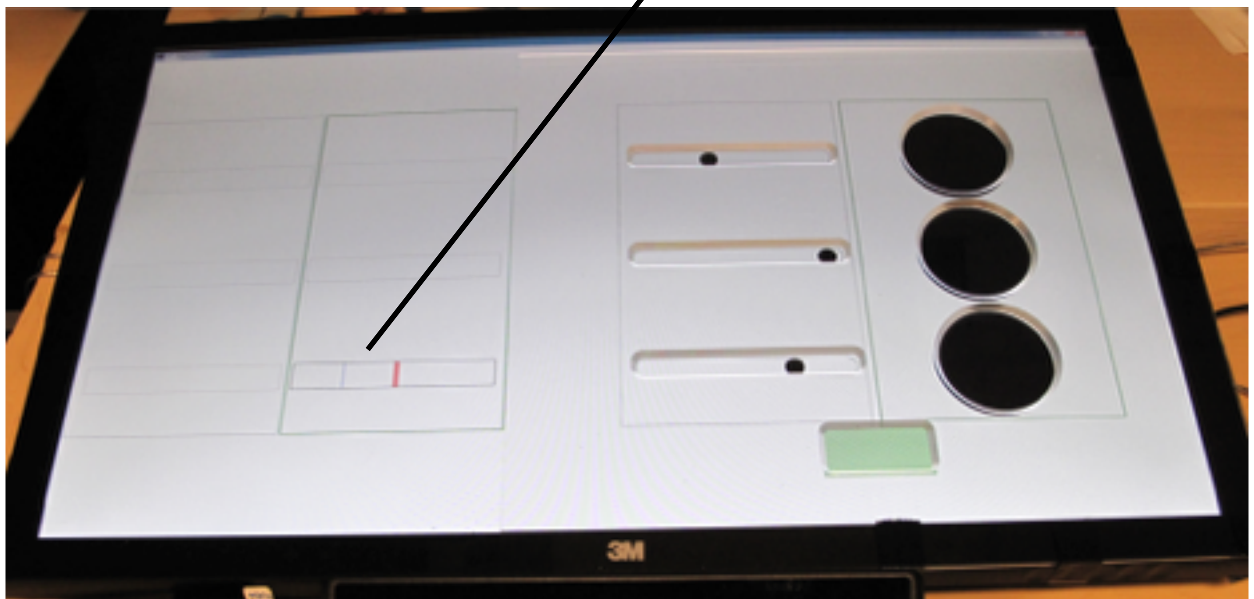


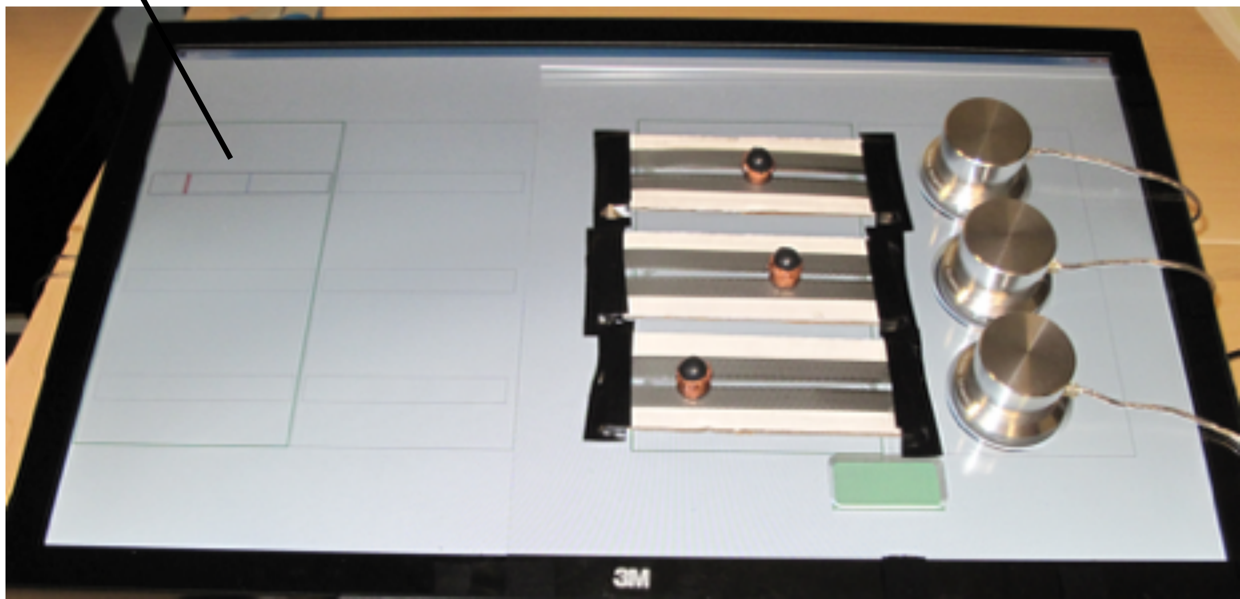
Tangible User Interfaces: What are they good for?

Several experiments demonstrated their benefits

Tangible User Interfaces: Benefit over touch and overlay

Tasks: set horizontal position of cursor



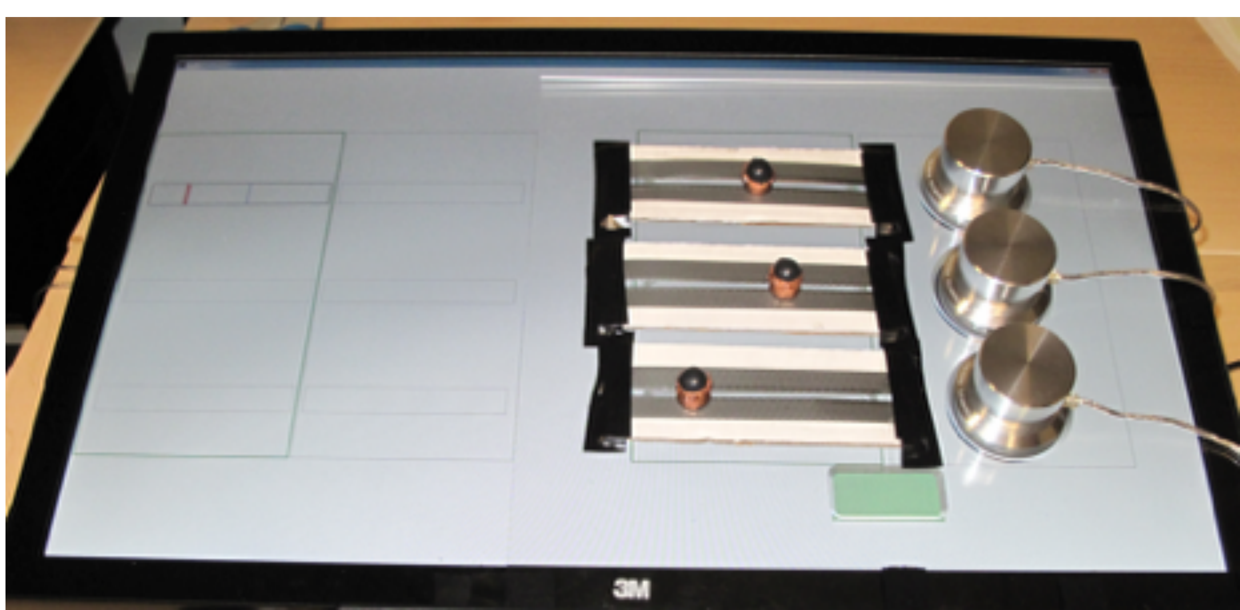


Tangible User Interfaces: Benefit over touch and overlay

Tasks: set horizontal position of cursor

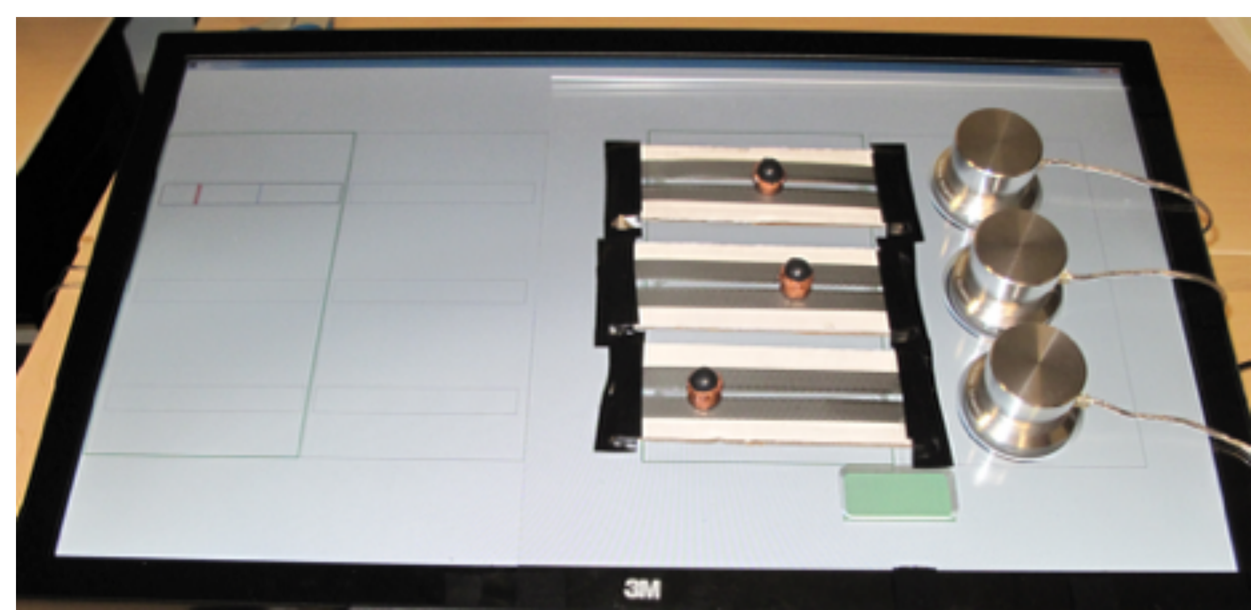
1. Press green button;
   Acquisition of required tool;
   Move towards and stay in target for 1 second;

2. Move cursor back and forth 5 times
   between two targets



Tangible User Interfaces: Benefit over touch and overlay

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



Tangible User Interfaces: Benefit over touch and overlay

- Task 1: acquisition and movement

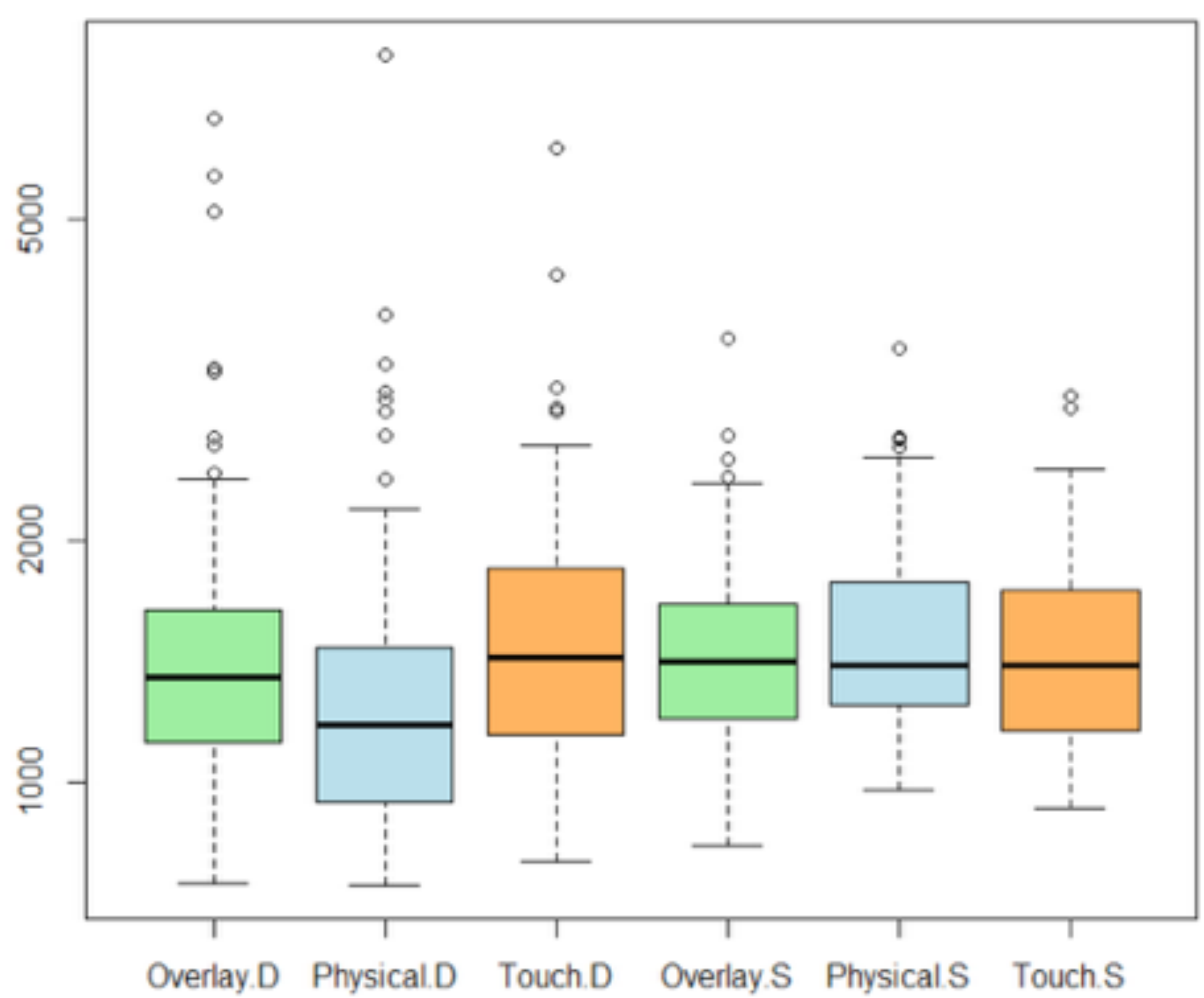
	Touch	Overlay	Tangible
Slider		?	
Single-turn dial			

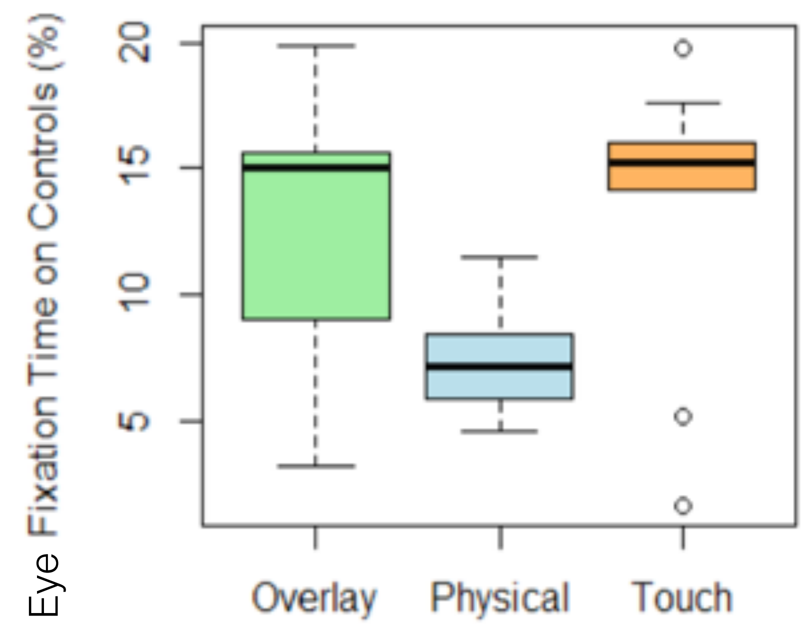
- Task 2: repetitive task

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

Tangible User Interfaces: Benefit over touch and overlay

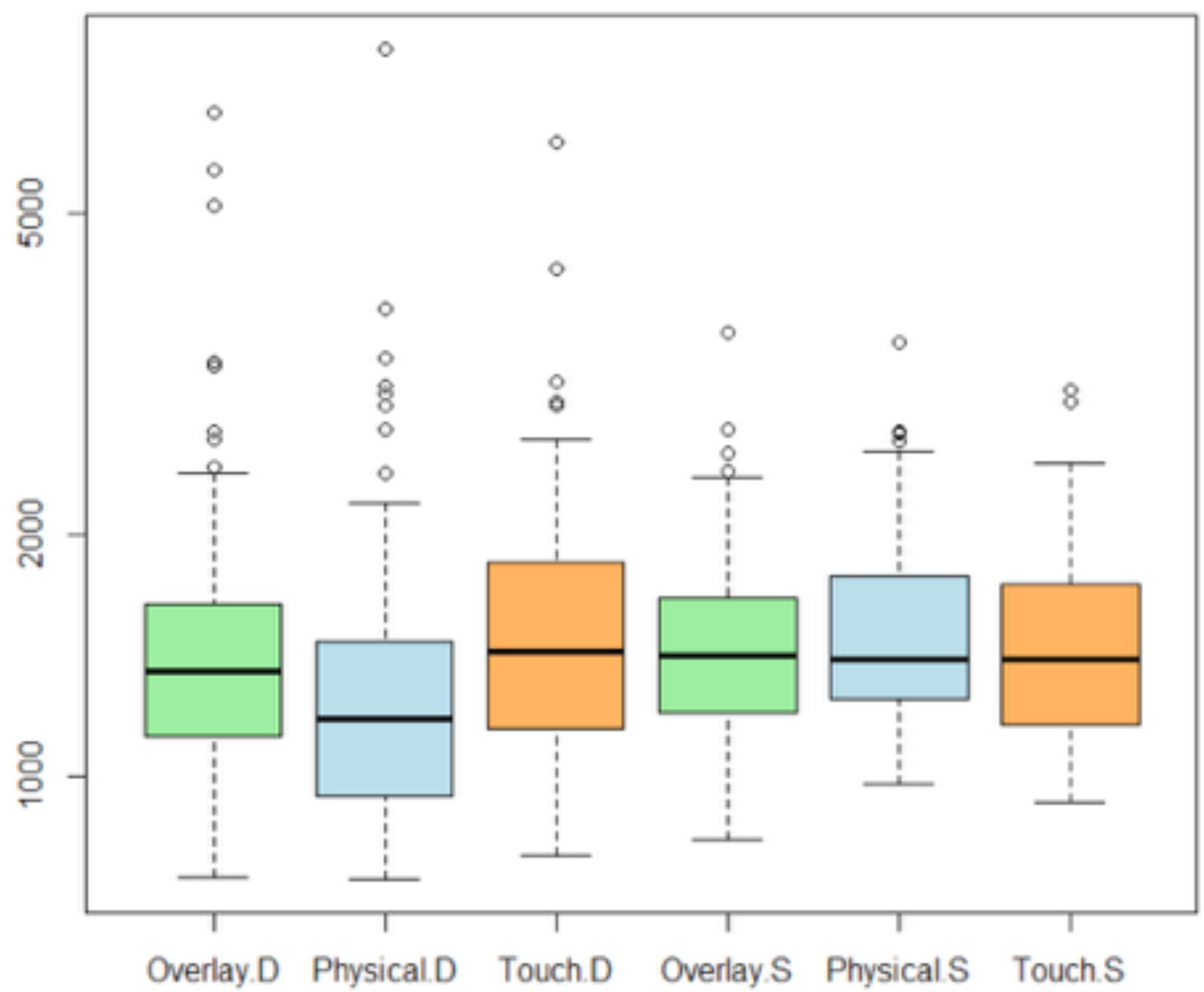
Task 1: acquisition and movement

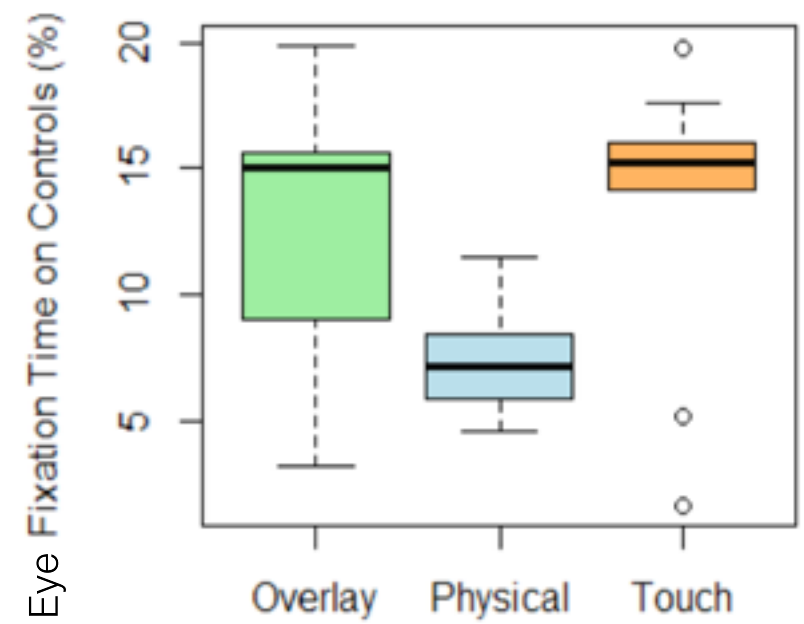




Tangible User Interfaces: Benefit over touch and overlay

Task 1: acquisition and movement

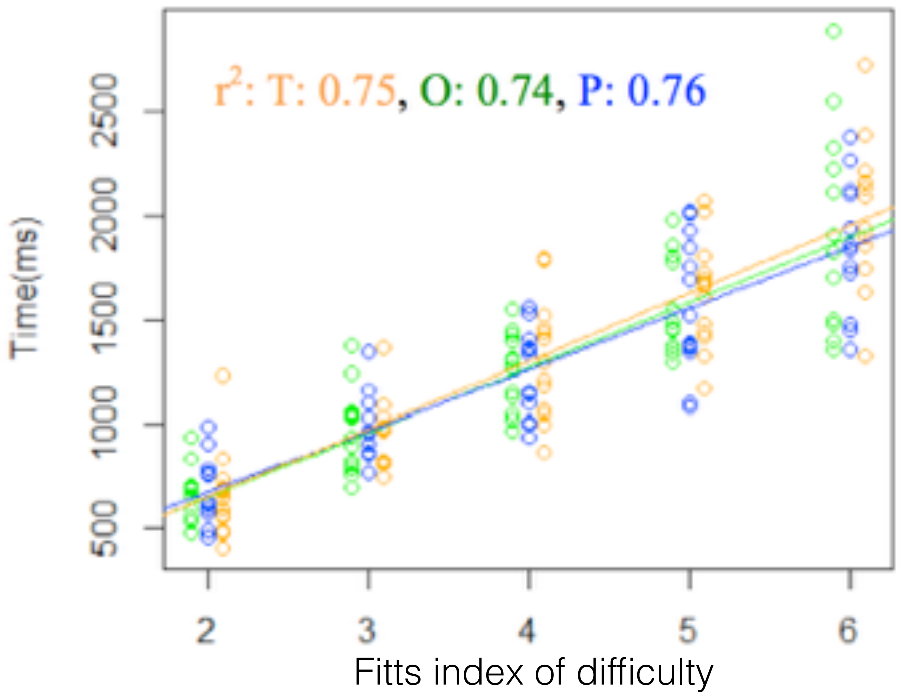




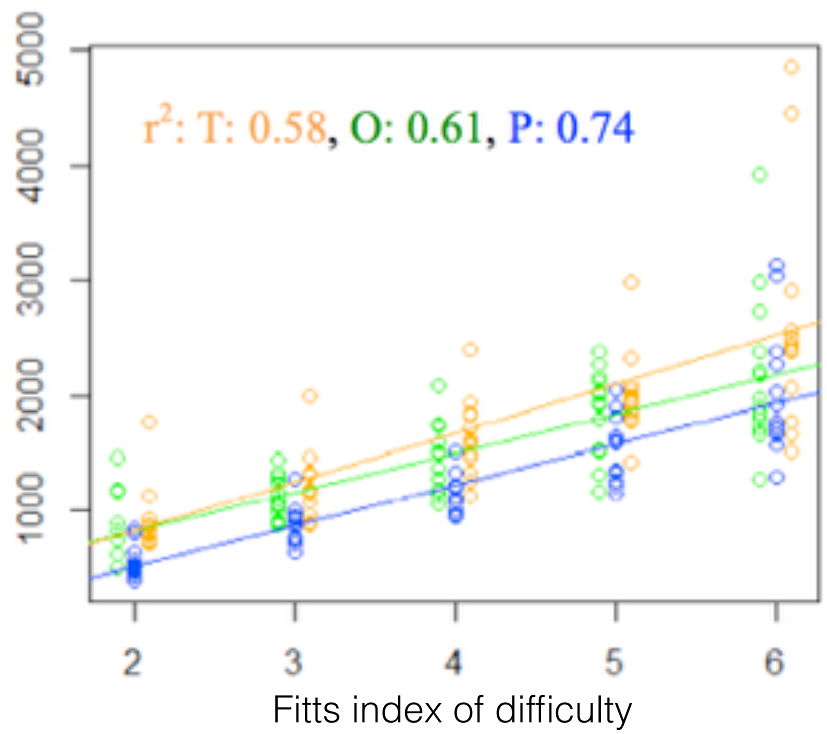
No difference found for sliders: because of manipulation problem with tangible sliders: *"participants complained that they were wobbly and required some pressure"*

Tangible User Interfaces: Benefit over touch and overlay

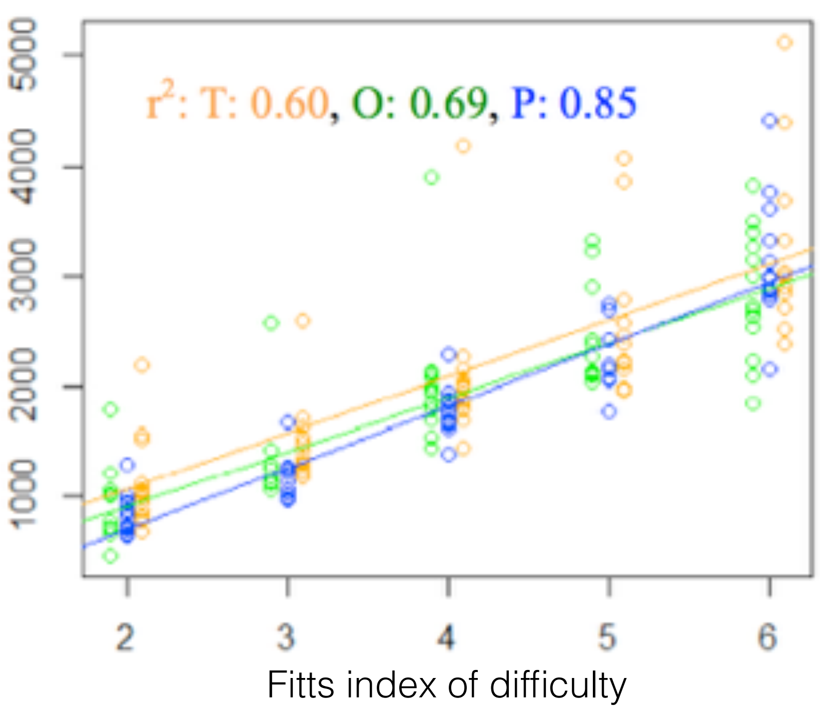
Task 2: Repetitive movement



Slider



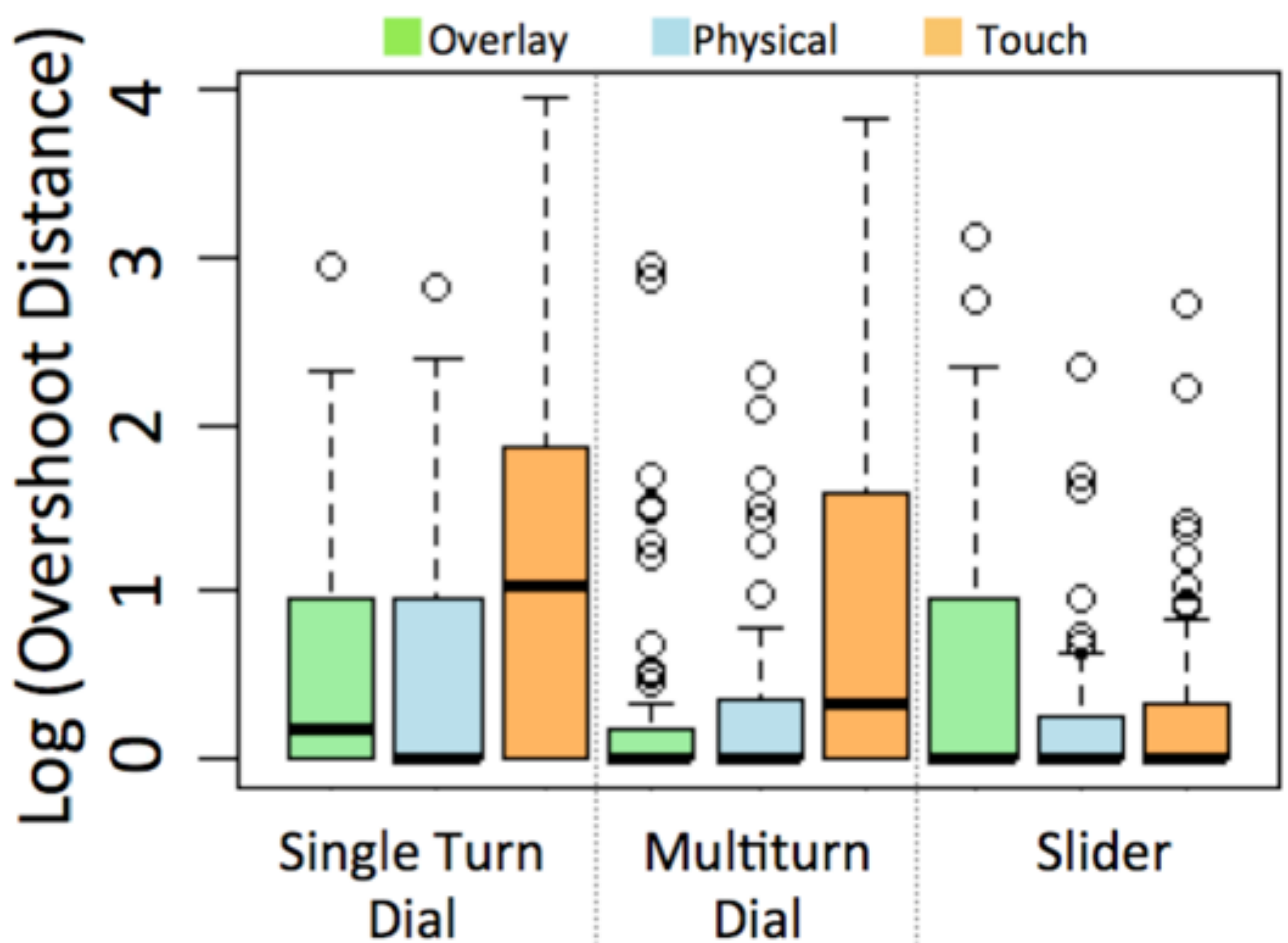
Single Turn Dial



Multiturn Dial

Tangible User Interfaces: Benefit over touch and overlay

Task 2: Repetitive movement



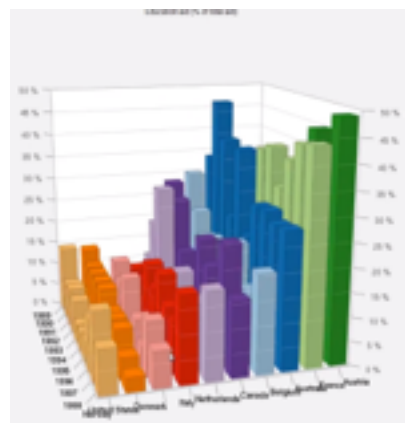
Tangible User Interfaces: What are they good for?

Several experiments demonstrated their benefits

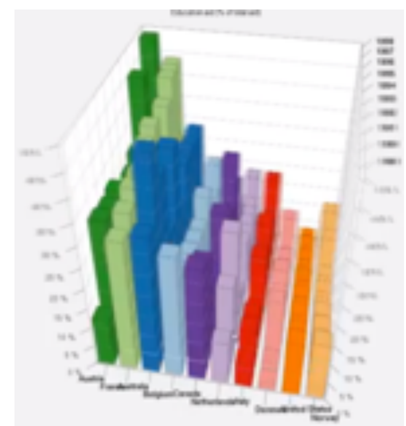
Tangible User Interfaces: What are they good for?

2D

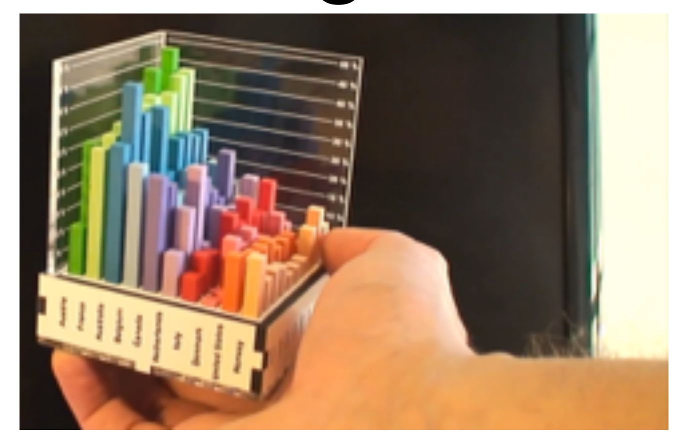
3D Mono



3D Stereo



Tangible



Tasks

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

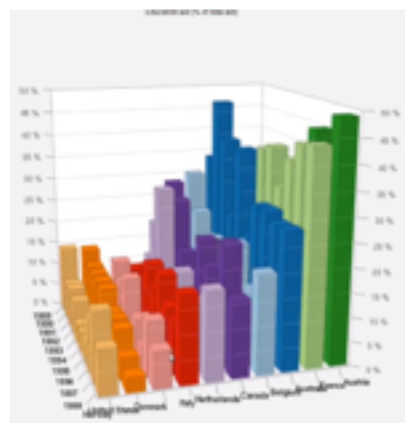
Measures

- Time
- Error rate

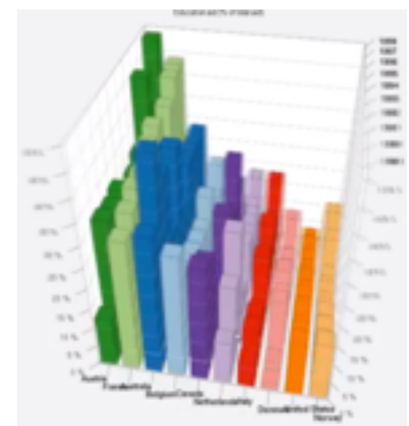
Tangible User Interfaces: What are they good for?

2D

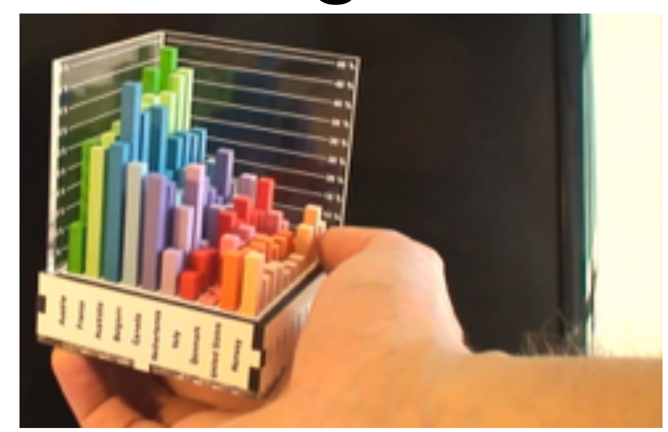
3D Mono



3D Stereo



Tangible

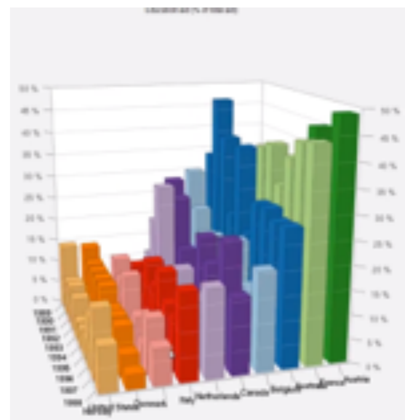


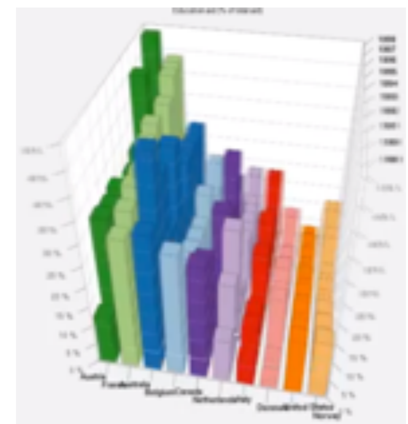
Users are:

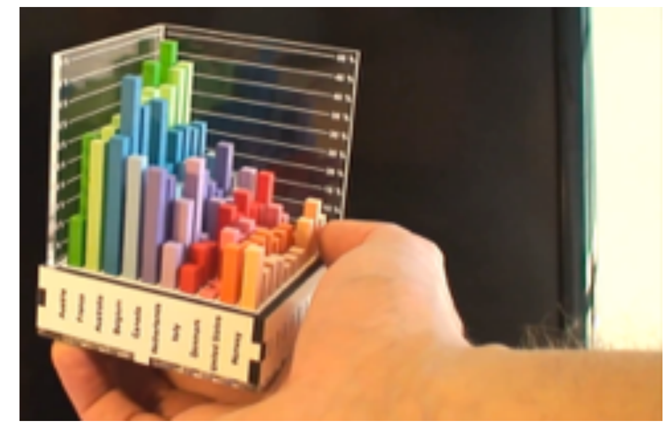
- Around 20% faster with Tangible than with 3D
- Around 40% faster with 2D than with Tangible
  - however, effect weaker if the task cannot be solved by one 2D cut

Tangible User Interfaces: What are they good for?

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

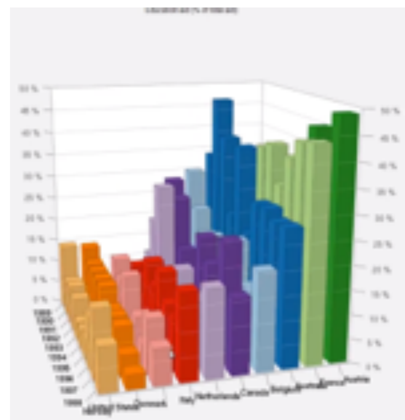
Proprioception

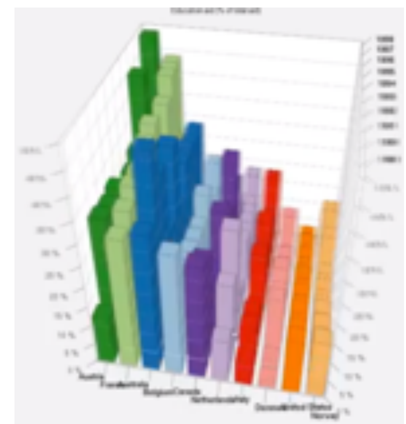
Definition:

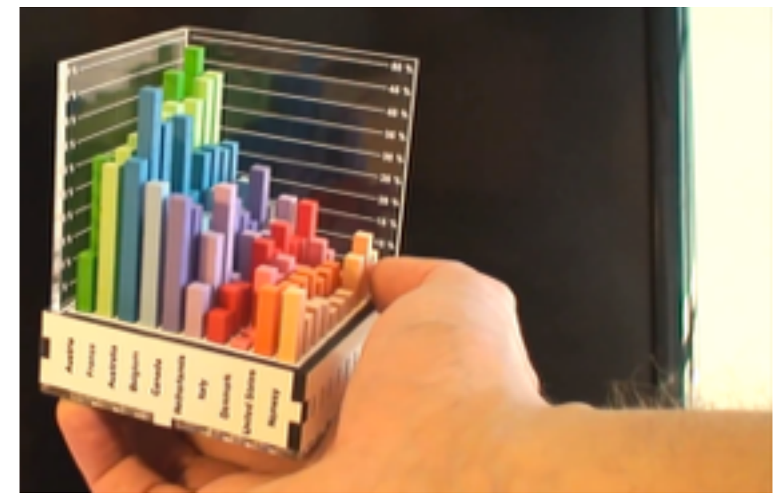
- Perception of our own body
- Sense of the relative position of our limbs through our skin, muscle, joints and inner ear

Tangible User Interfaces: What are they good for?

2D 3D Mono 3D Stereo Tangible





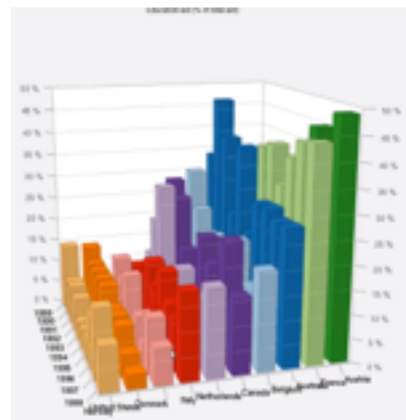
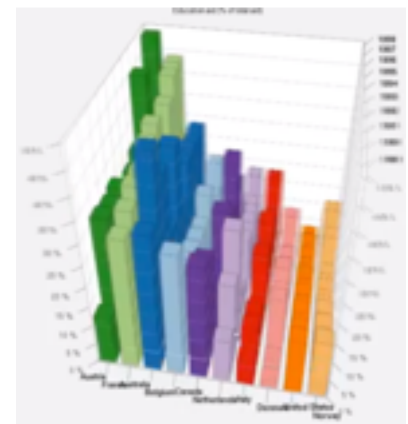
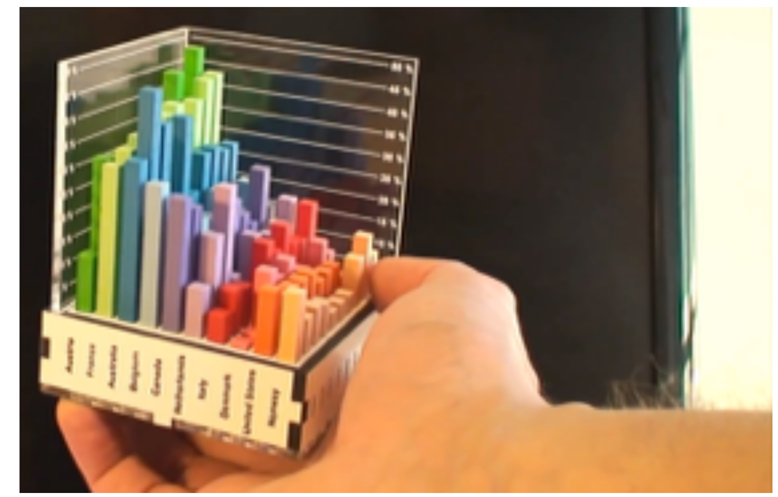


Among possible explanation: Direct rotation

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

Tangible User Interfaces: What are they good for?

2D 3D Mono 3D Stereo Tangible

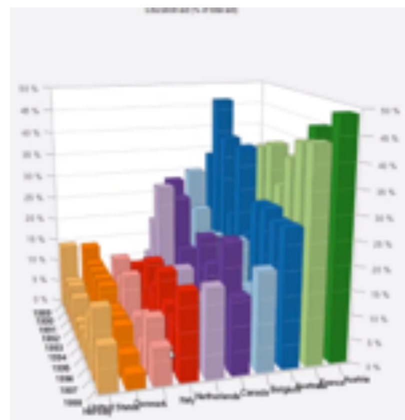





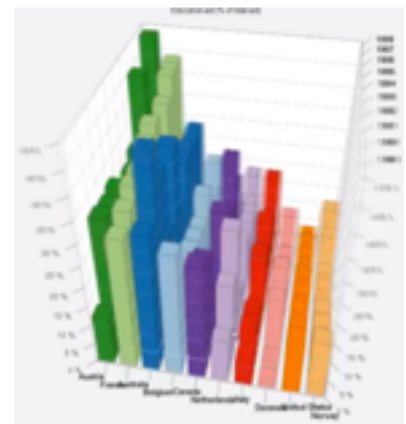
Among possible explanation: Visual Realism

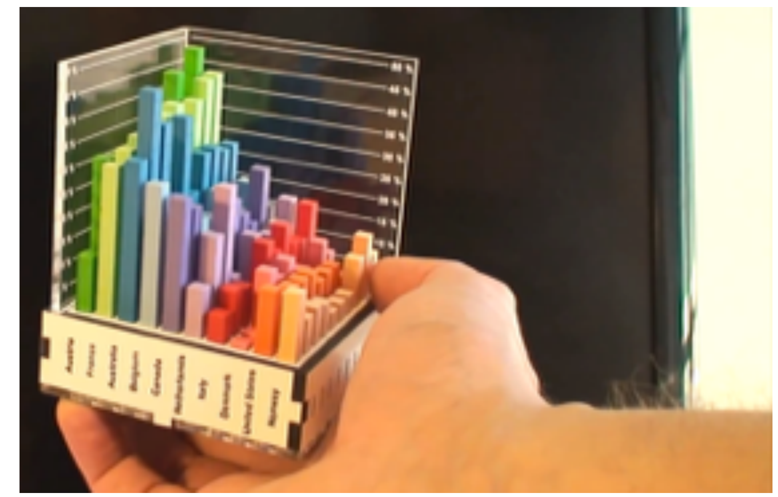
	3D mono/stereo	Tangible
Resolution	1920 x 1080 px for 23”	0.5mm
Stereoscopic cues (Images L and R different)	no / yes	yes
Accomodation cues	at screen distance	at any distance
Shading and shadows	computer-generated	natural
Texture	none	spray paint imperfections

Tangible User Interfaces: What are they good for?

2D 3D Mono 3D Stereo Tangible



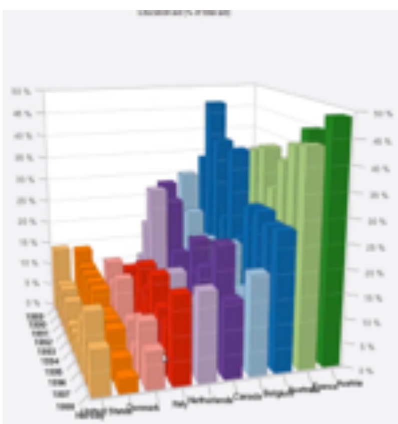




Impact of all possible explanations?

- Touch & Proprioception?
- Direct rotation?
- Visual Realism?

Tangible User Interfaces: What are they good for?

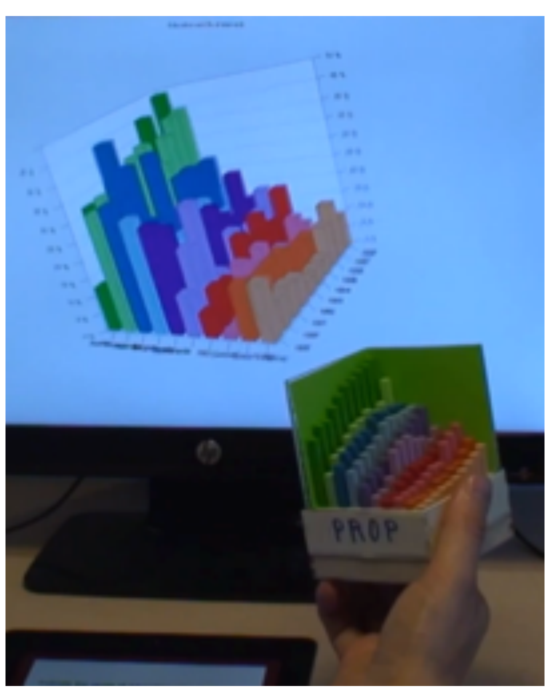


3D Mono &
Indirect mouse rotation &
No bar marking

Tangible
Direct rotation
& Touch

Direct rotation

Touch &
Proprioception



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

Tangible
Direct rotation &
No touch

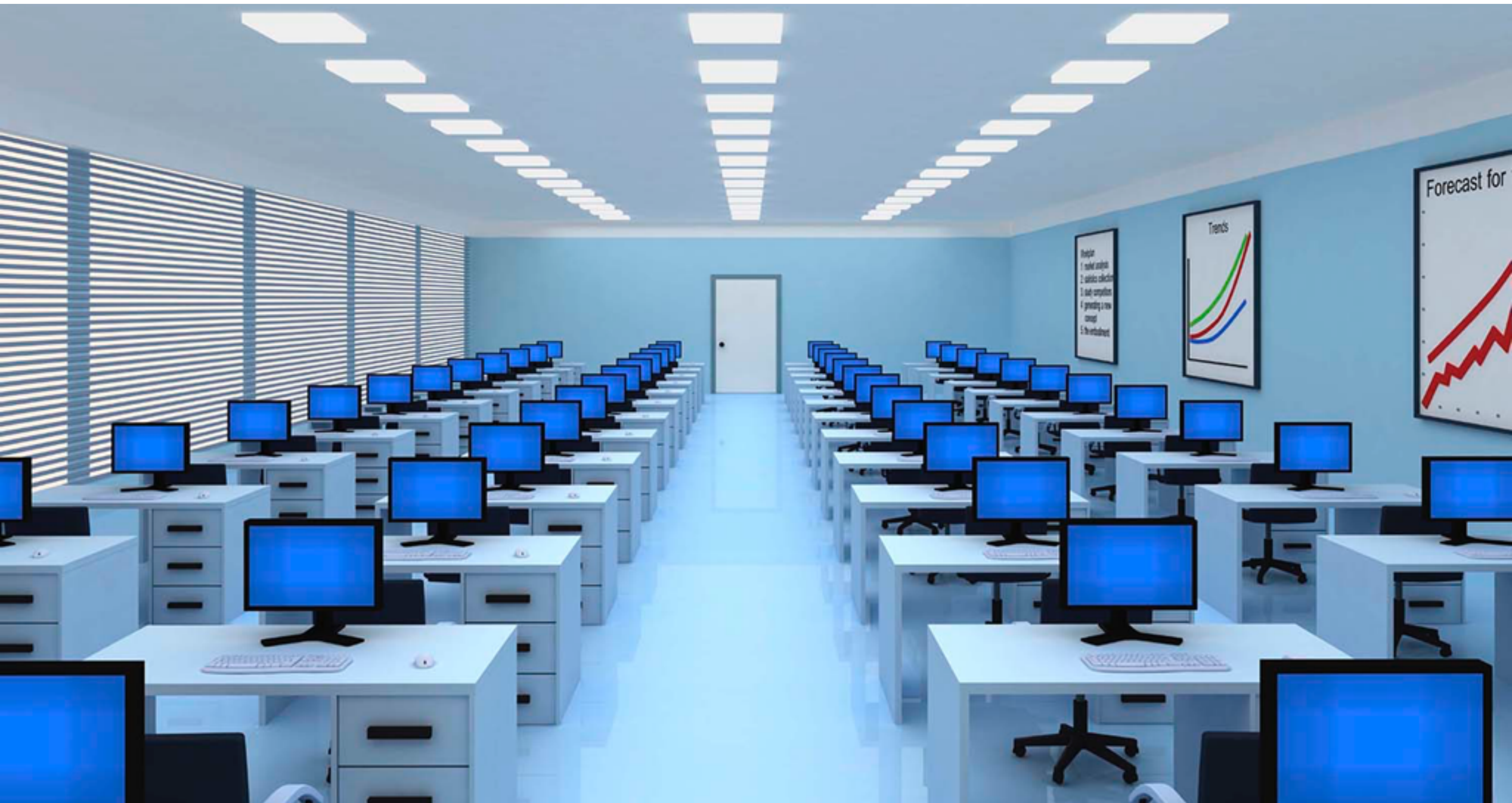
Visual realism

Tangibles User Interfaces: What are they good for?

- 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 their limitations?

Graphical > Tangible?



Graphical > Tangible?

- Dynamicity, Flexibility
- Price

Graphical > Tangible?

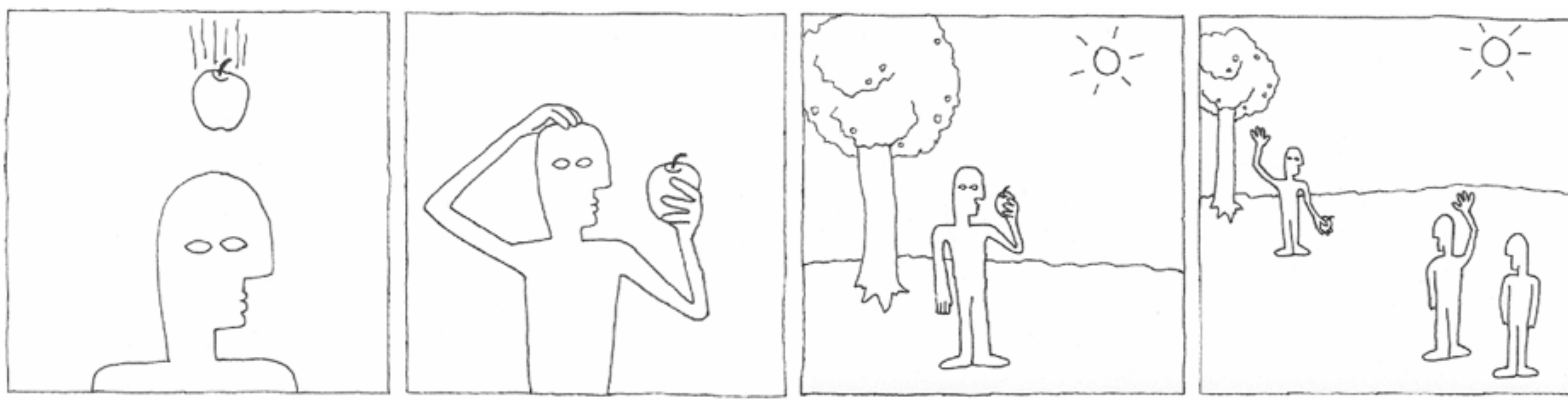
- Reality based interaction
  - Compromise with software when it brings benefit

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



Naïve Physics | Body Awareness & Skills | Environment Awareness & Skills | Social Awareness & Skills

Reality Based Interaction


Naïve Physics

E.g., gravity, friction, velocity

Example of interfaces using users' knowledge of naive physics?

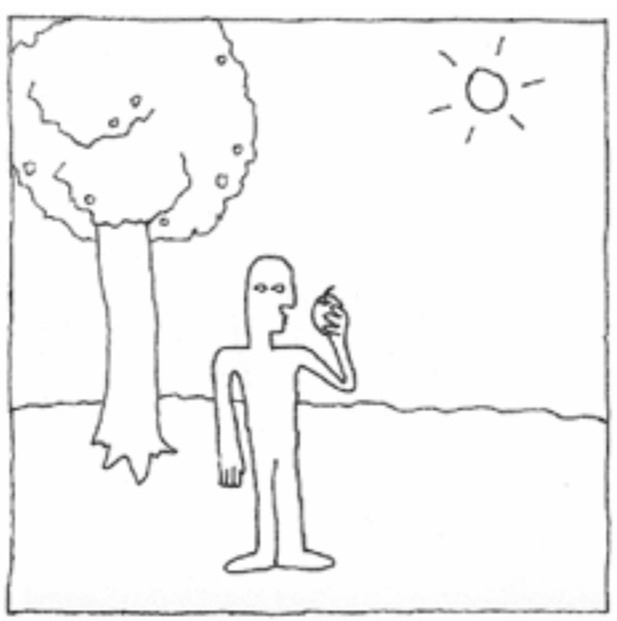
Reality Based Interaction

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

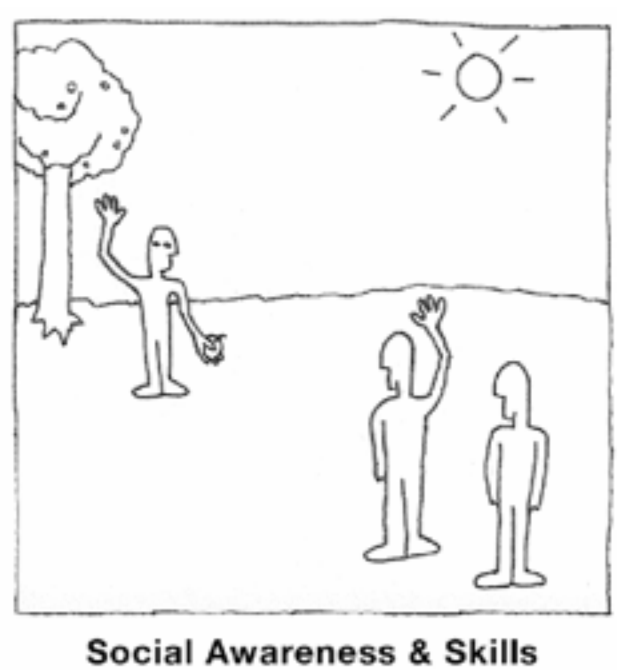


Environment Awareness & Skills

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



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

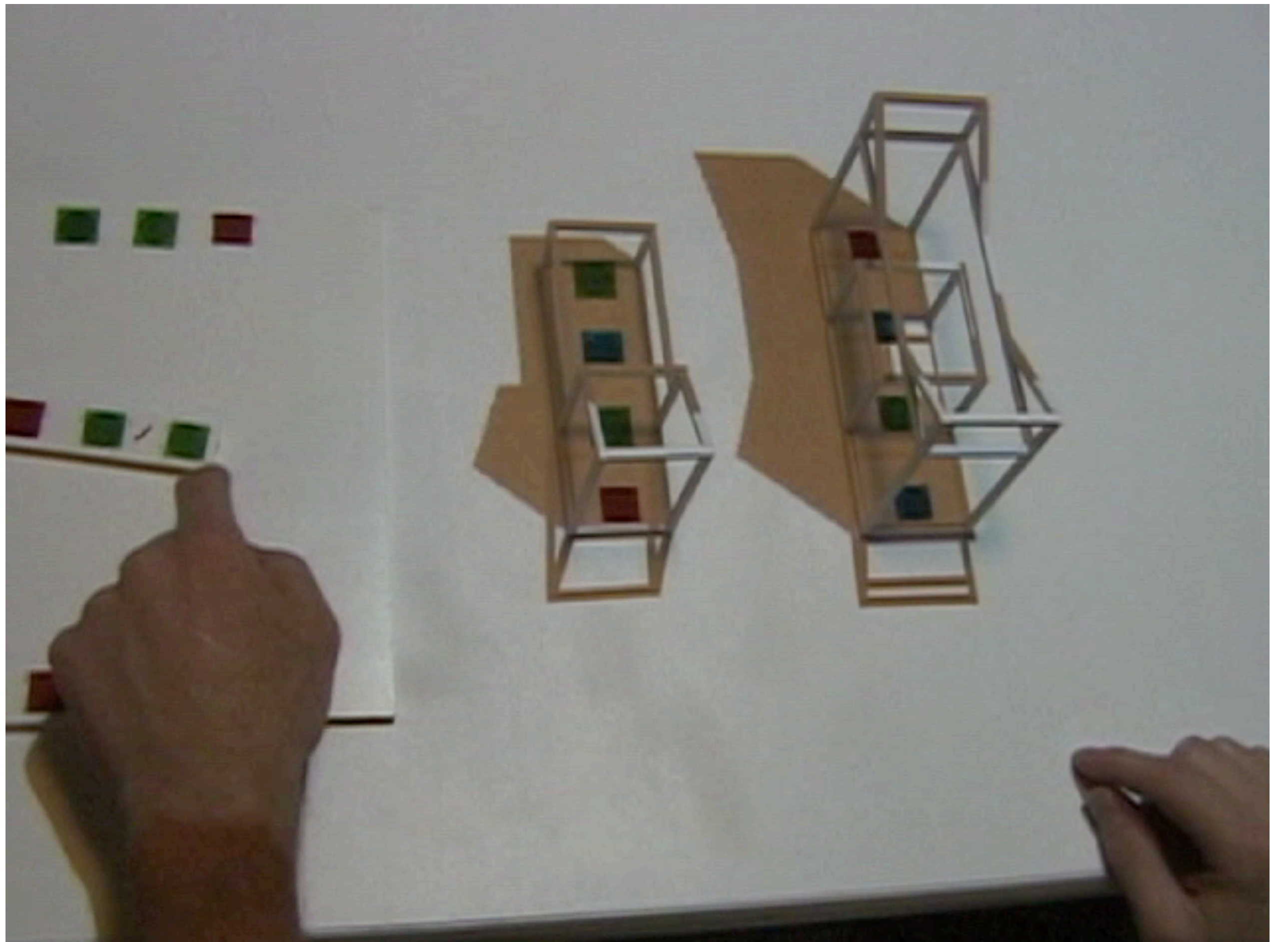
Practicality
(designers) ability to produce the system

Reality Based Interaction

Case study: URP

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

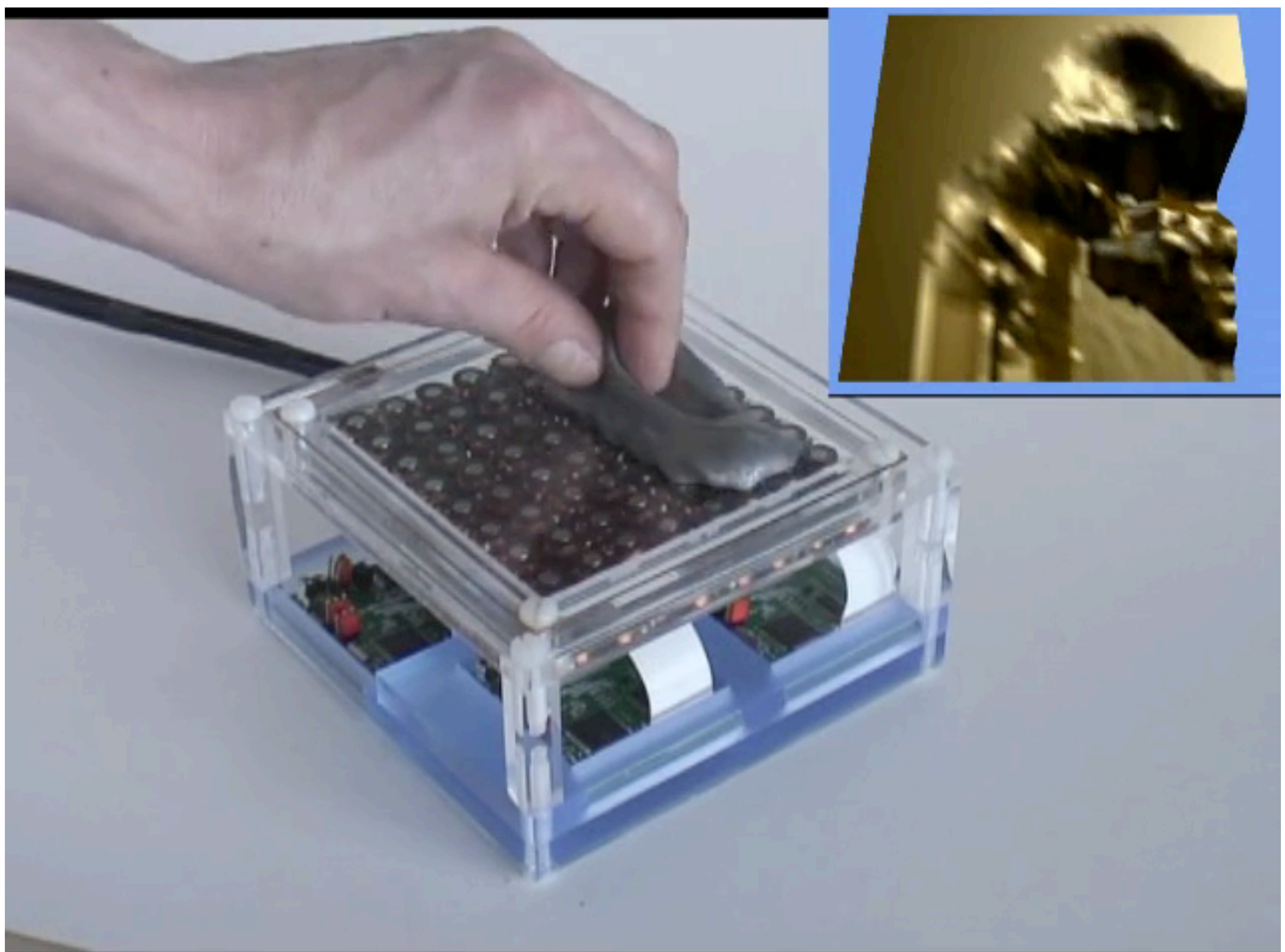
How can we benefit again from Tangibility?

BREAK

- Focus group

Dynamicity & Flexibility: Shape

A Reconfigurable Ferromagnetic Input Device



Dynamicity & Flexibility: Shape

SandScape

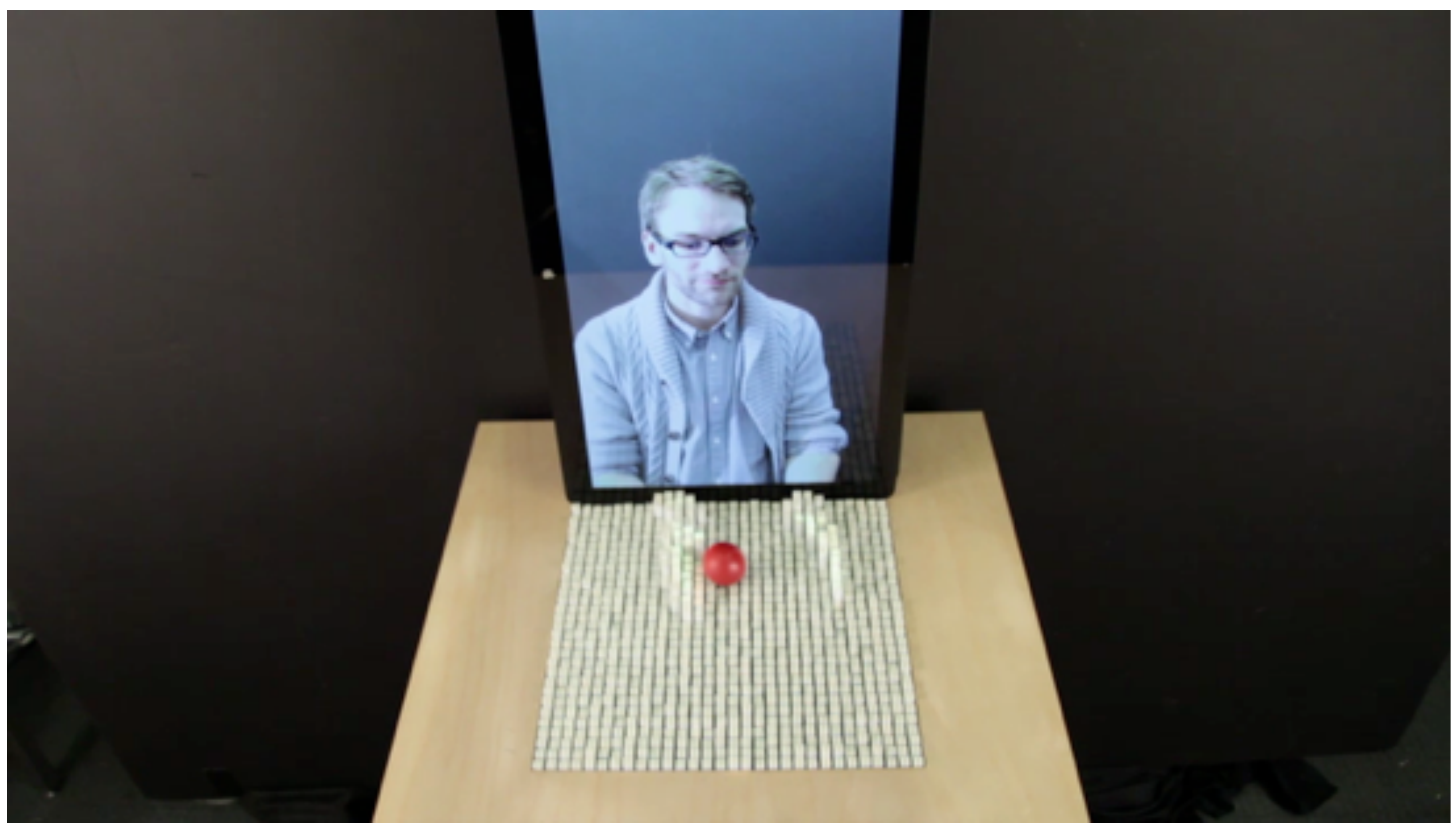
Dynamicity & Flexibility: Shape

Illuminating Clay

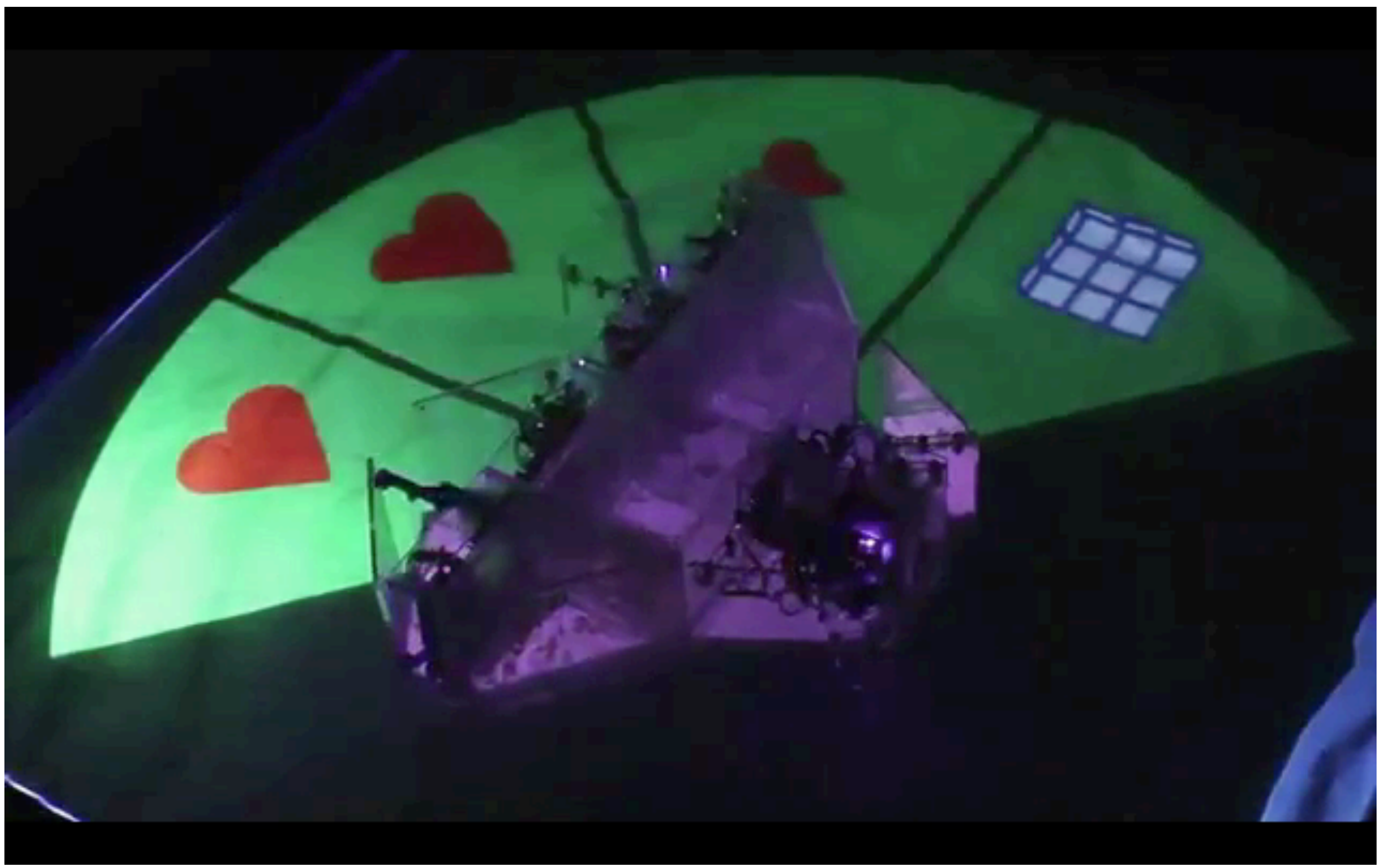
Dynamicity & Flexibility: Shape

Dynamically changeable buttons:
http://www.youtube.com/watch?v=Smai_Z_galE

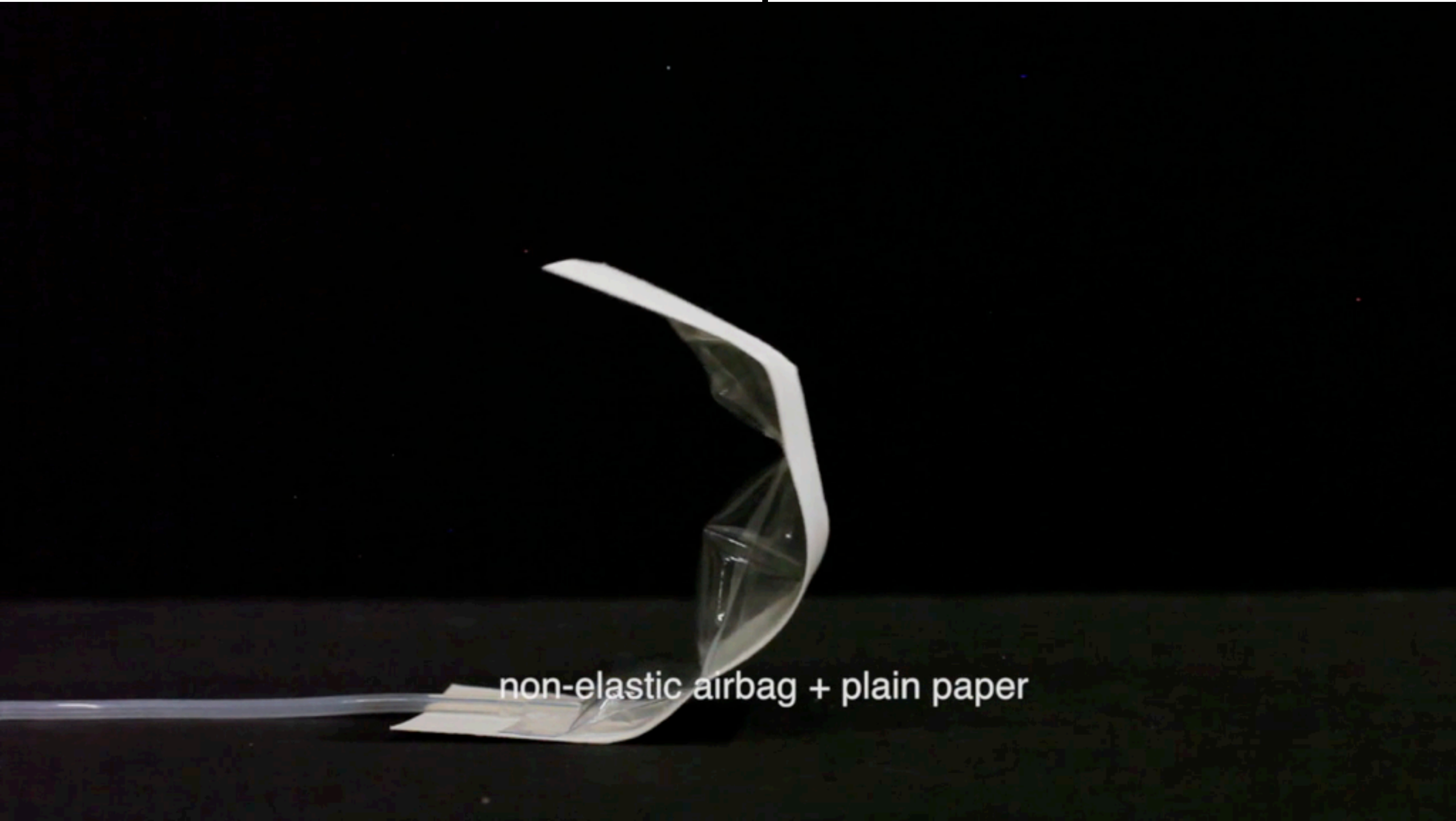
Dynamicity & Flexibility: Shape



Dynamicity & Flexibility: Shape



Dynamicity & Flexibility: Shape



Dynamicity & Flexibility: Shape

Dynamicity & Flexibility: Shape

Dynamicity & Flexibility: Shape

Shutters with shape memory alloy

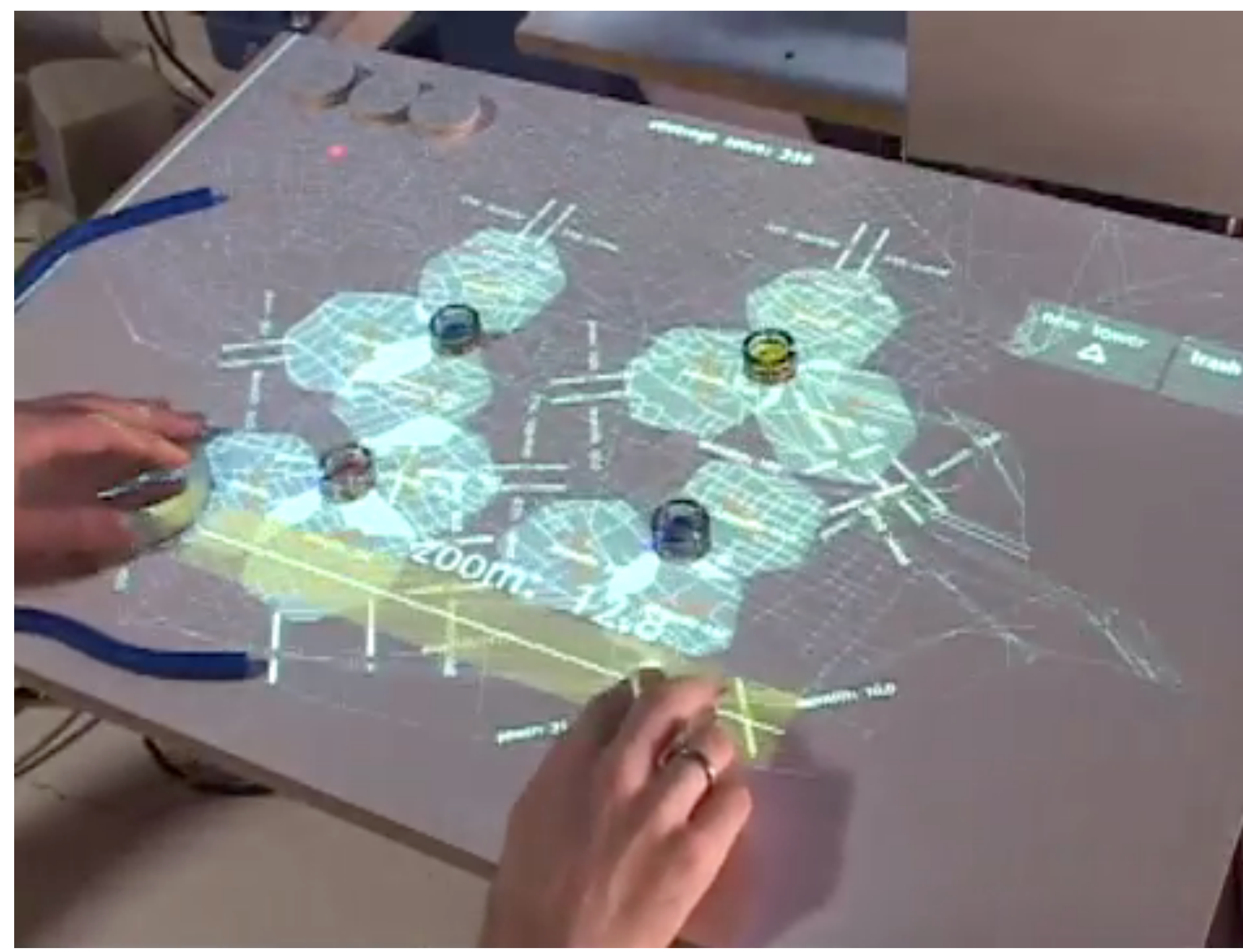
Dynamicity & Flexibility: Shape

with nanoscopic cells

Dynamicity & Flexibility: 2D location

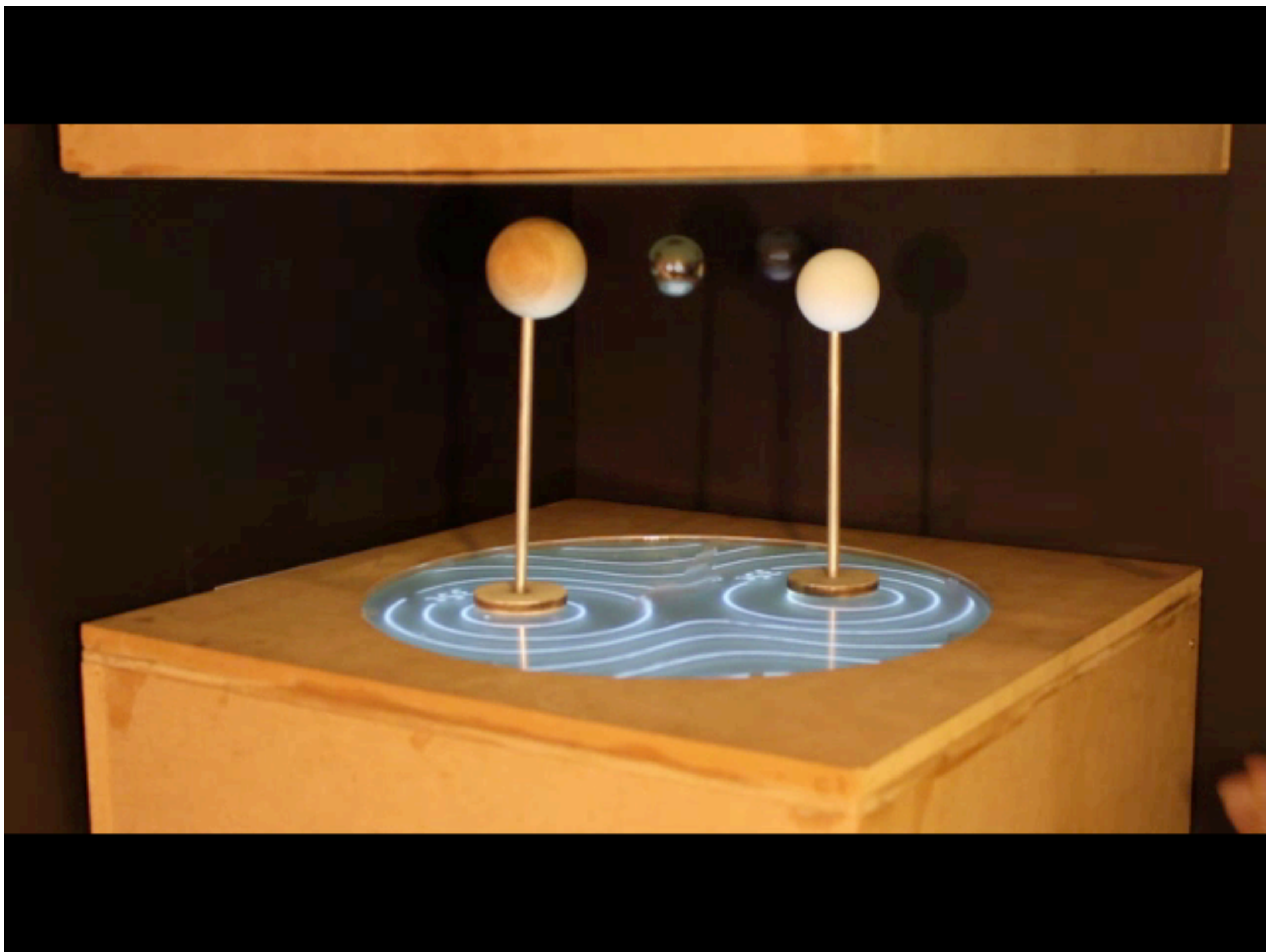
Actuated workBench

PICO

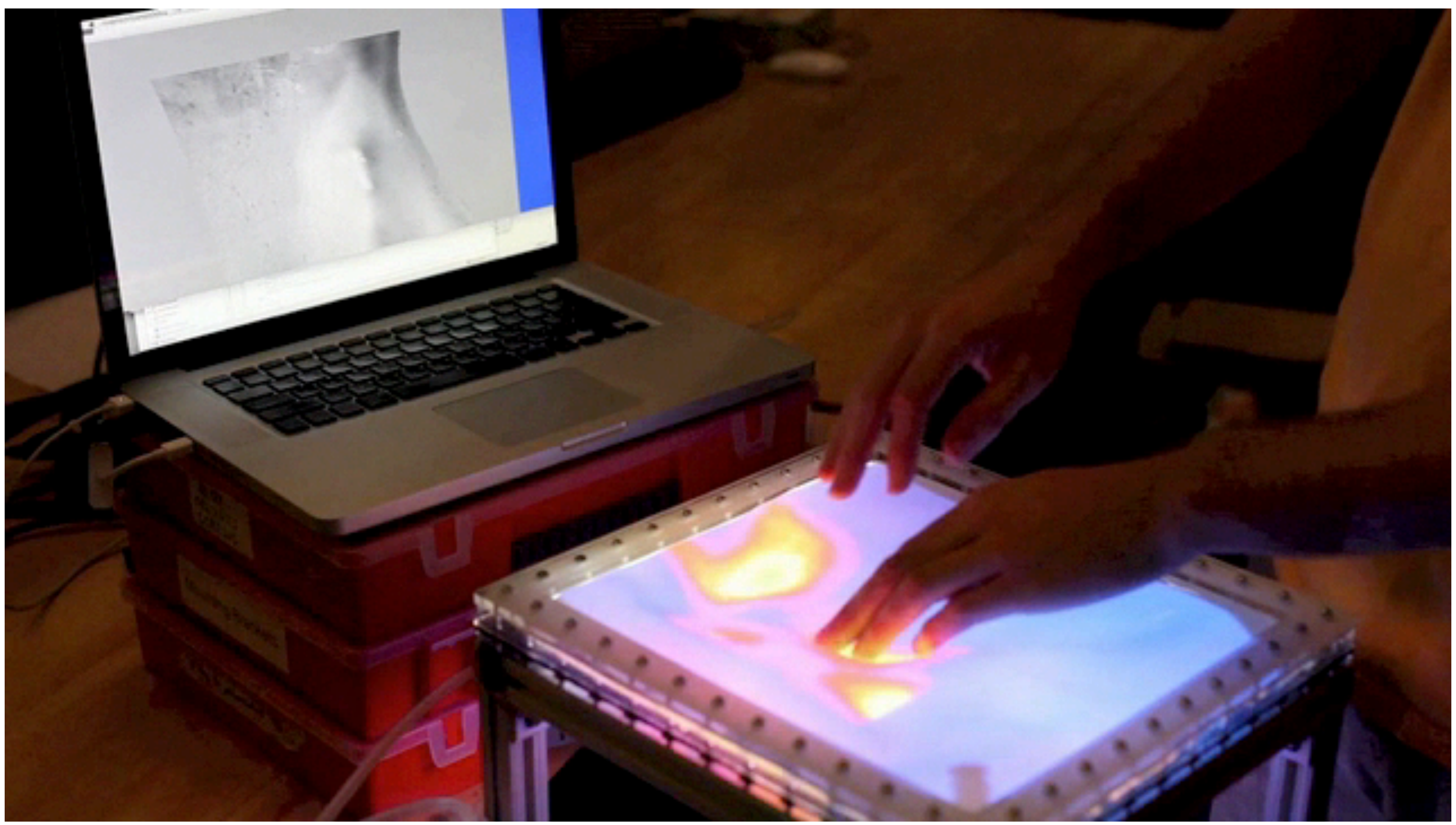


Dynamicity & Flexibility: 3D location

(several technologies)



Dynamicity & Flexibility: Stiffness



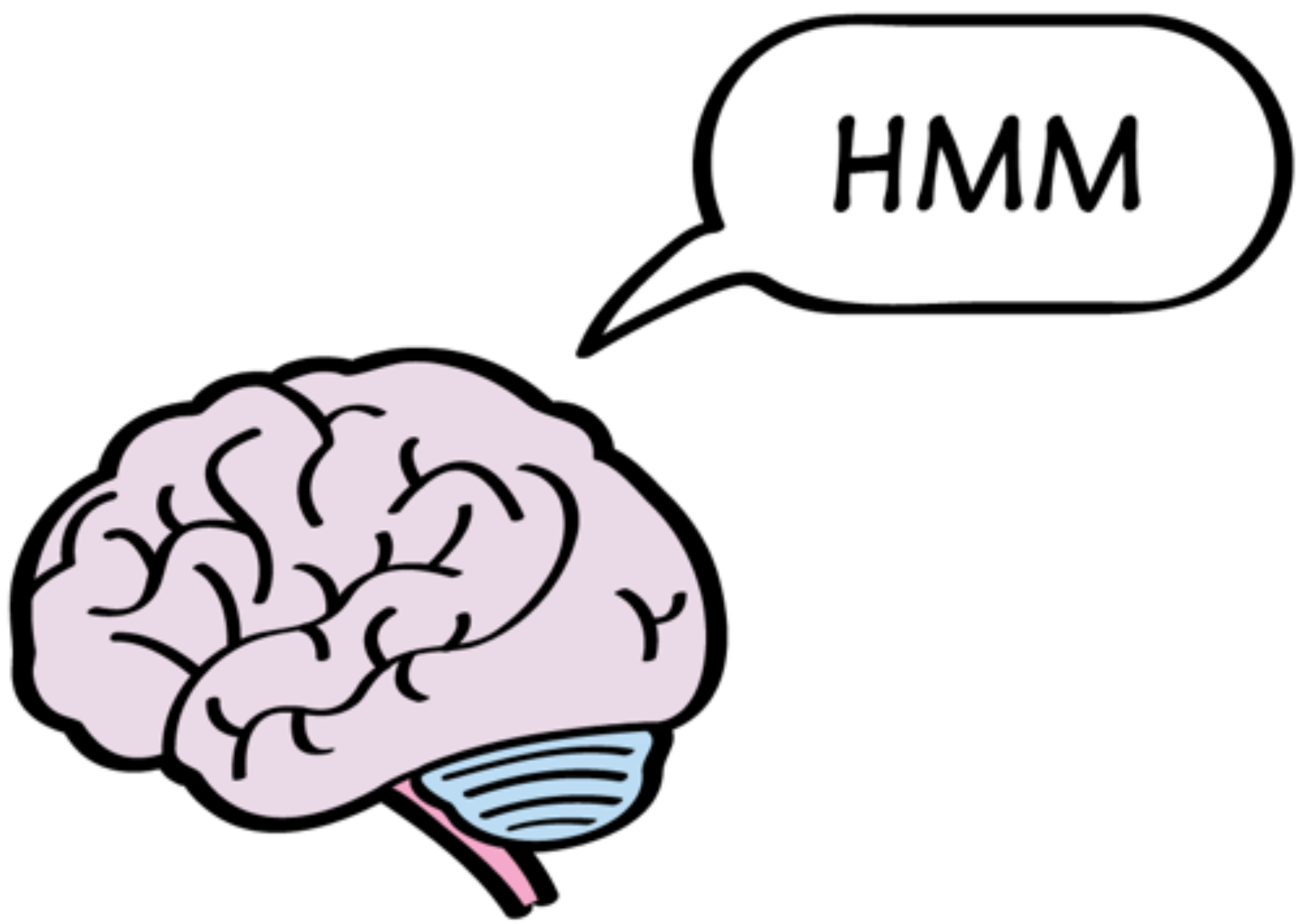
Dynamicity & Flexibility: Stiffness

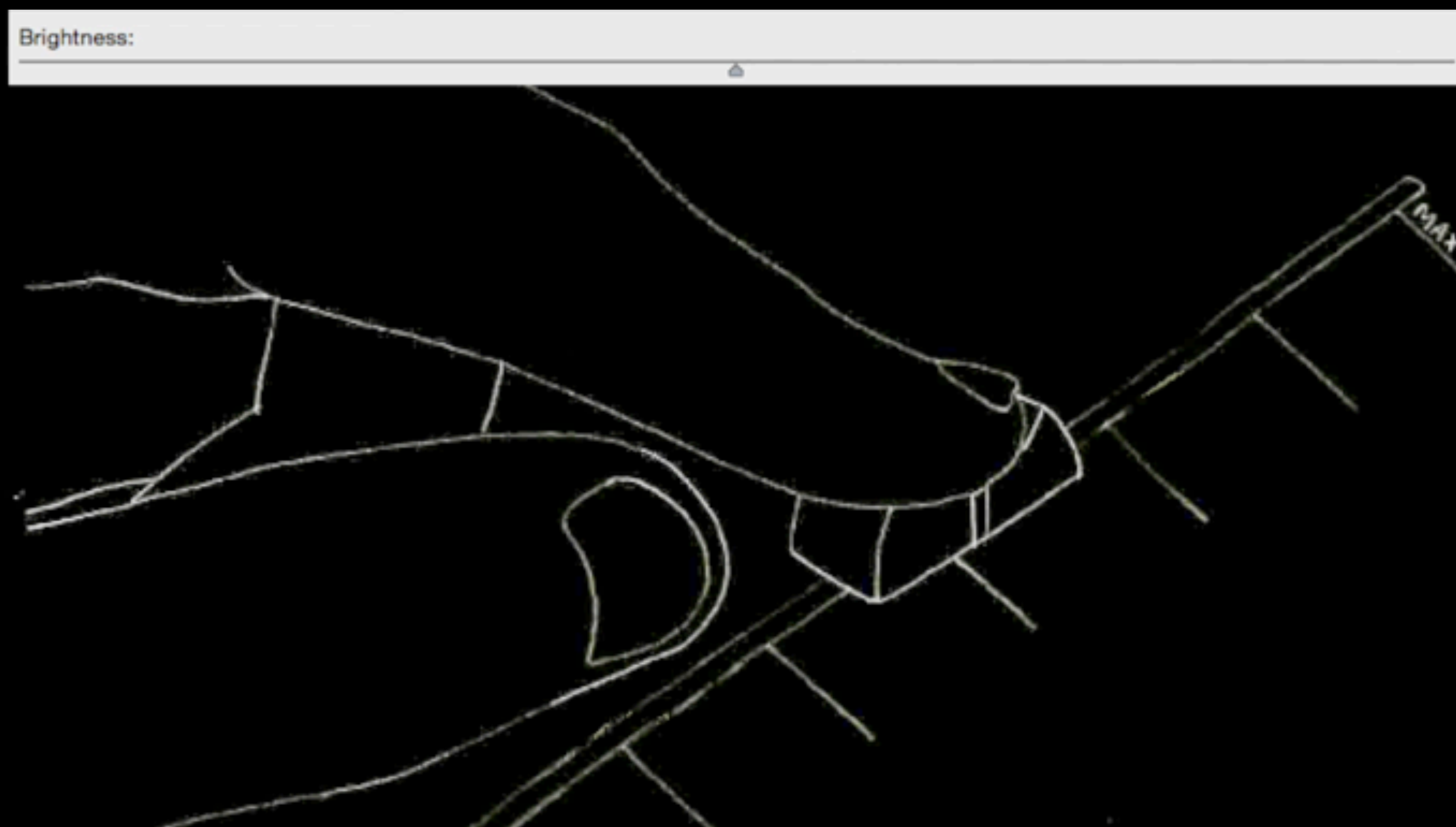
3D Printing Pneumatic Device Controls
with Variable Activation Force Capabilities

https://youtu.be/-4gFYvhkz0Y

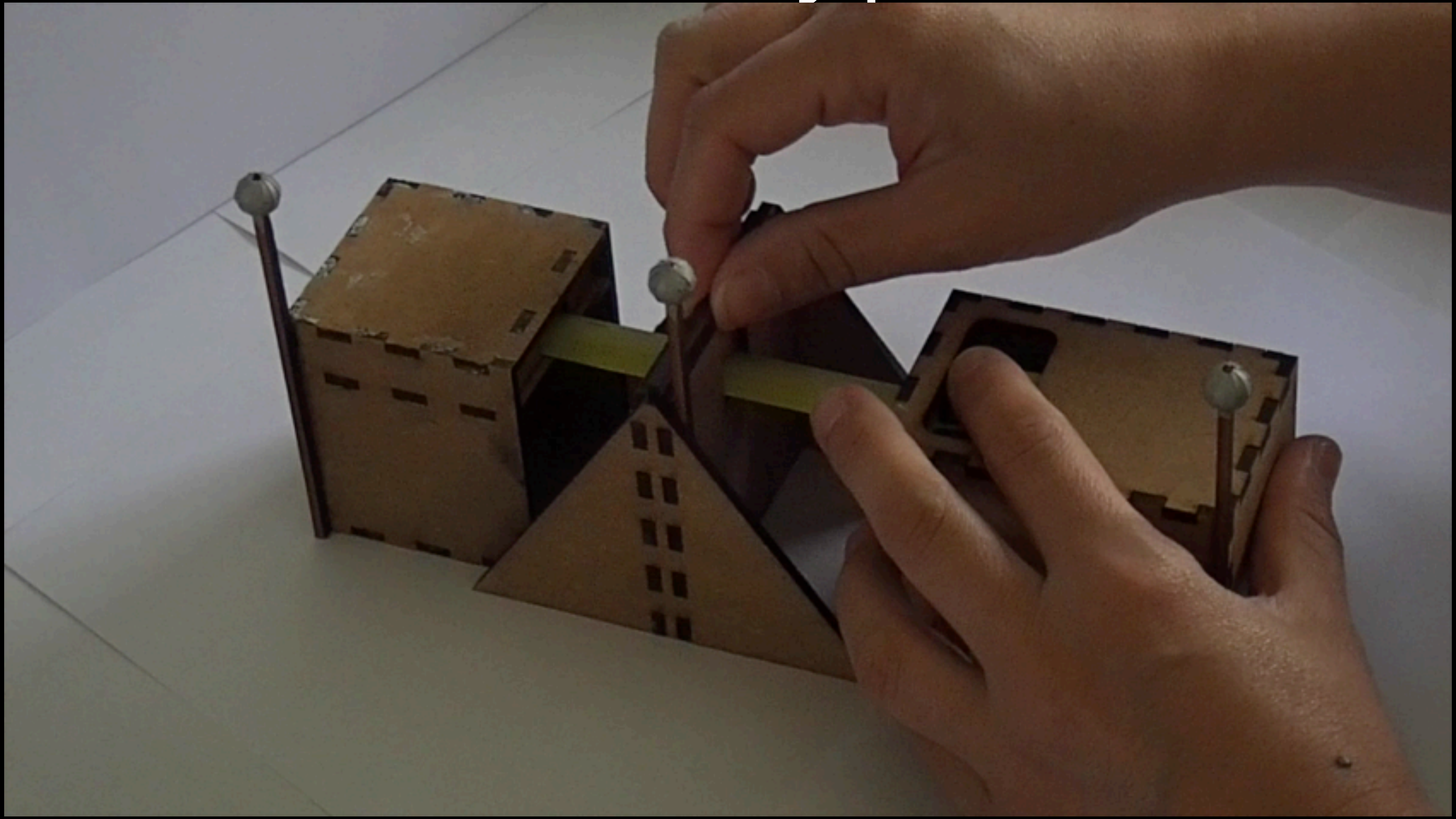
Dynamicity & Flexibility: Weight

Dynamicity & Flexibility: What is is good for?




Brightness:
MAX

Prototype



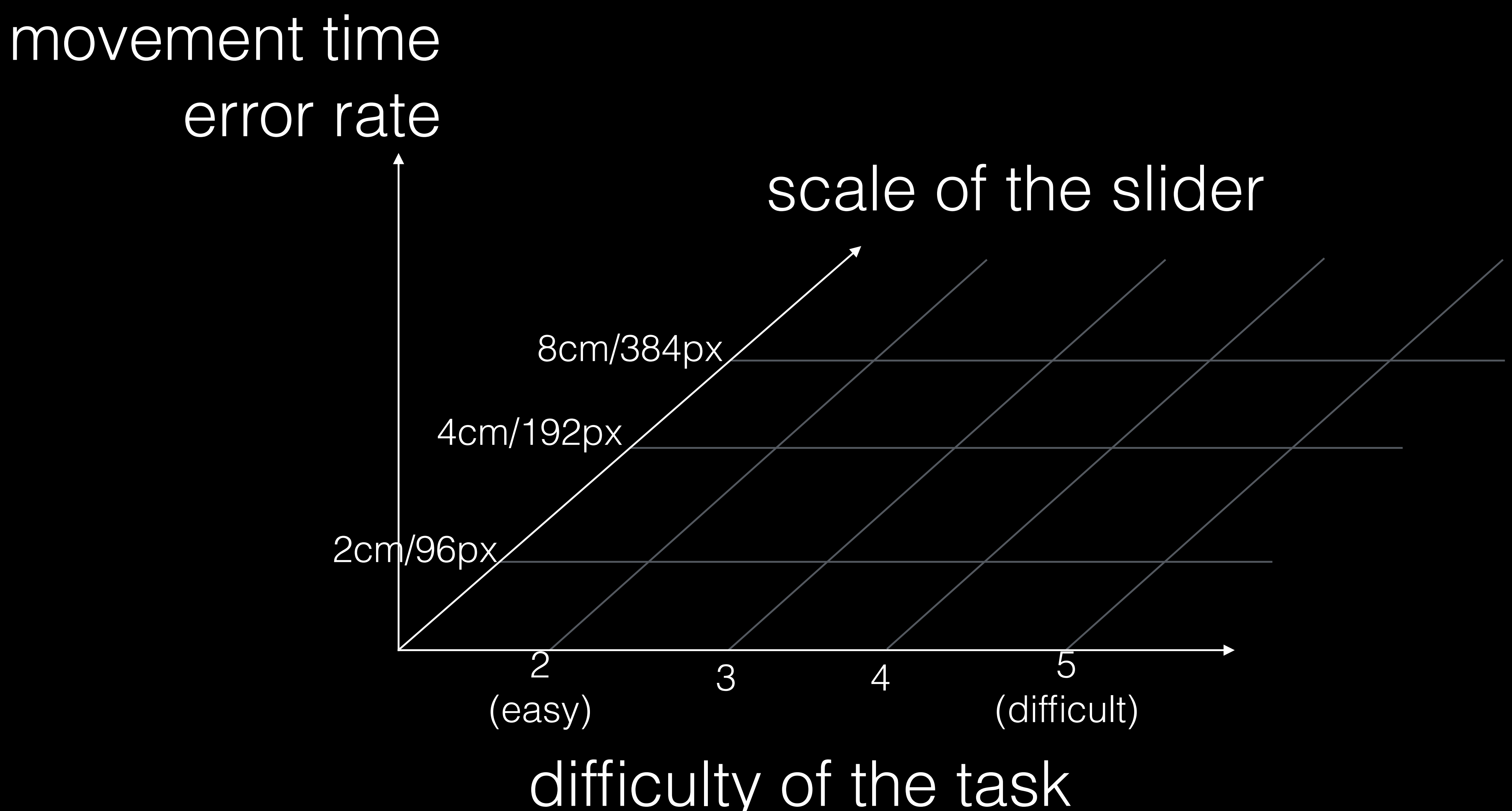
Prototype

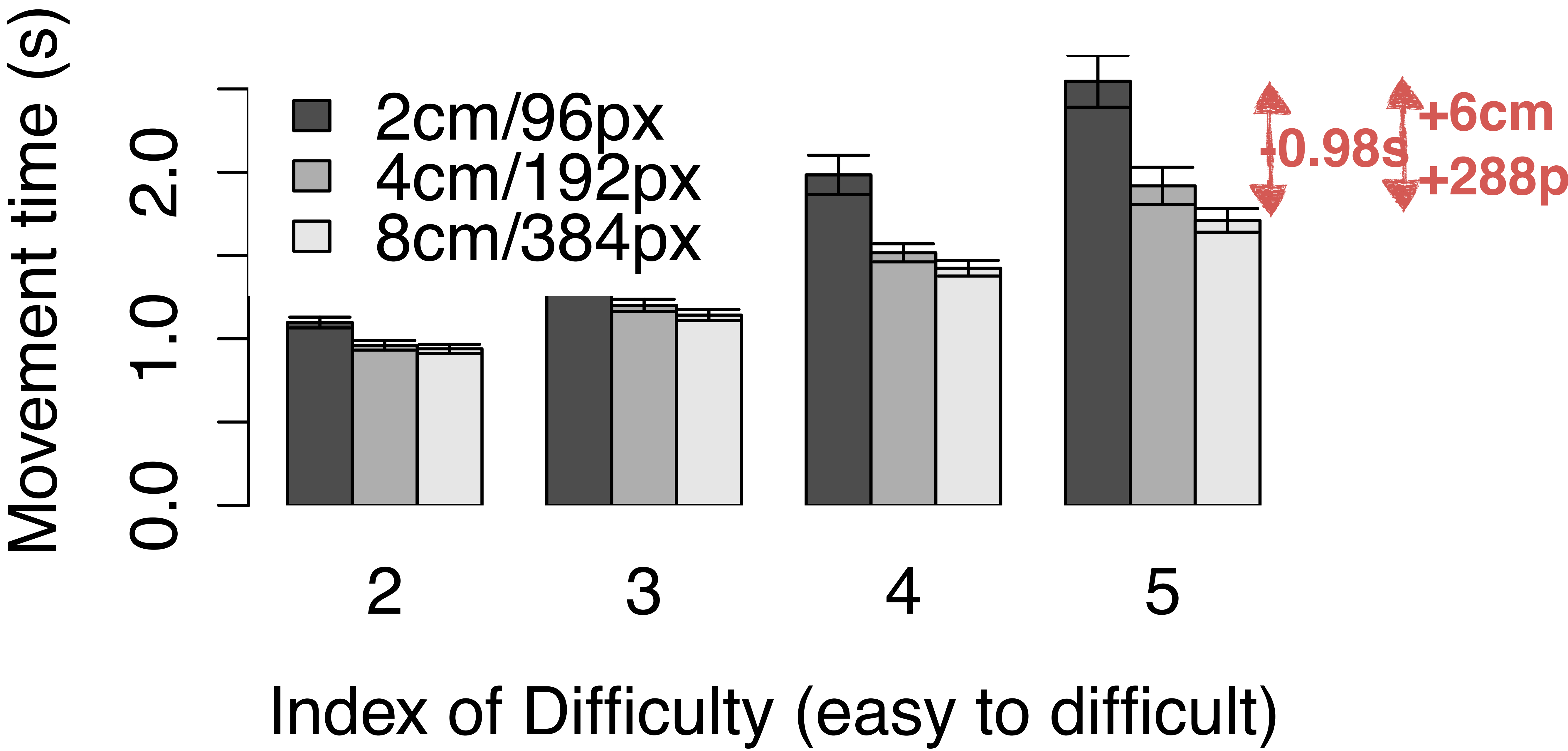
resolution: 2822 dpi

Benefit of Multiple Sizes: Experiment 1

How much more efficient are users
with a large slider than a small slider?

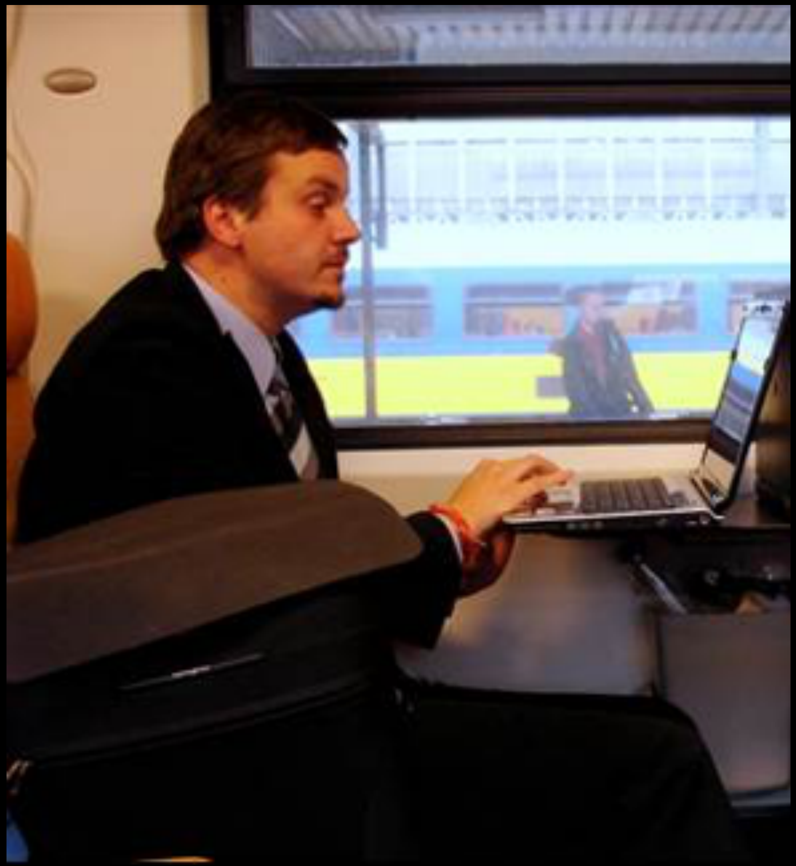
Benefit of Multiple Sizes: Experiment 1




Movement time (s)
0.0
1.0
2.0
2cm/96px
4cm/192px
8cm/384px
-0.98s
+6cm
+288p
2
3
4
5
Index of Difficulty (easy to difficult)

Zoomed in is better

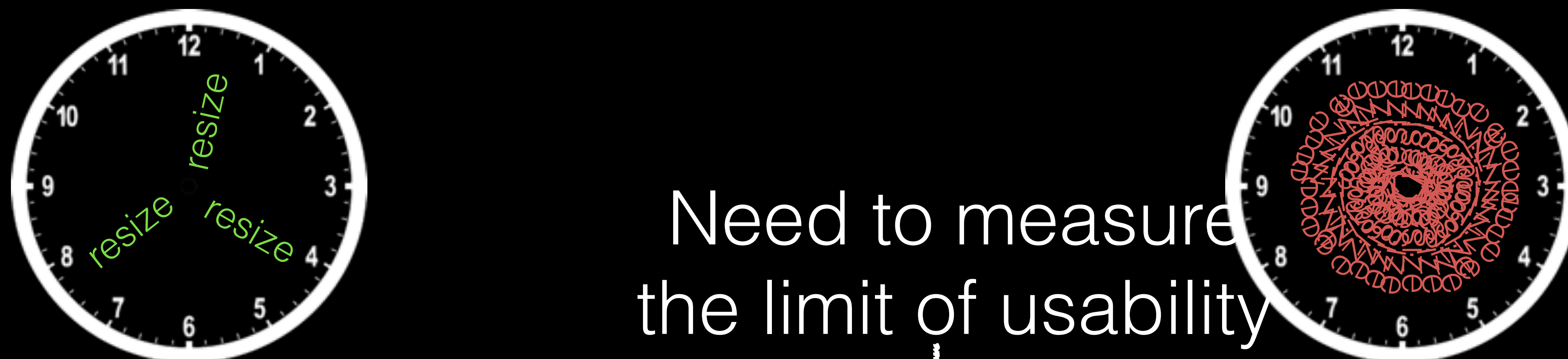
not possible when workspace is restricted



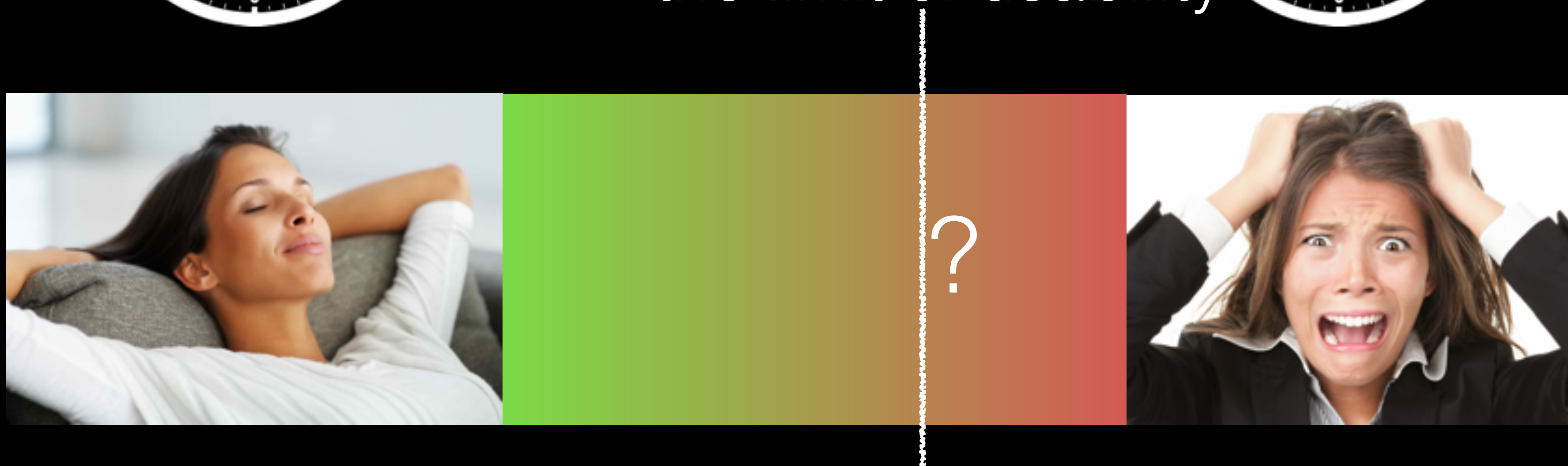
Drawback of resizing: Experiment 2

Impact of resizing on performance

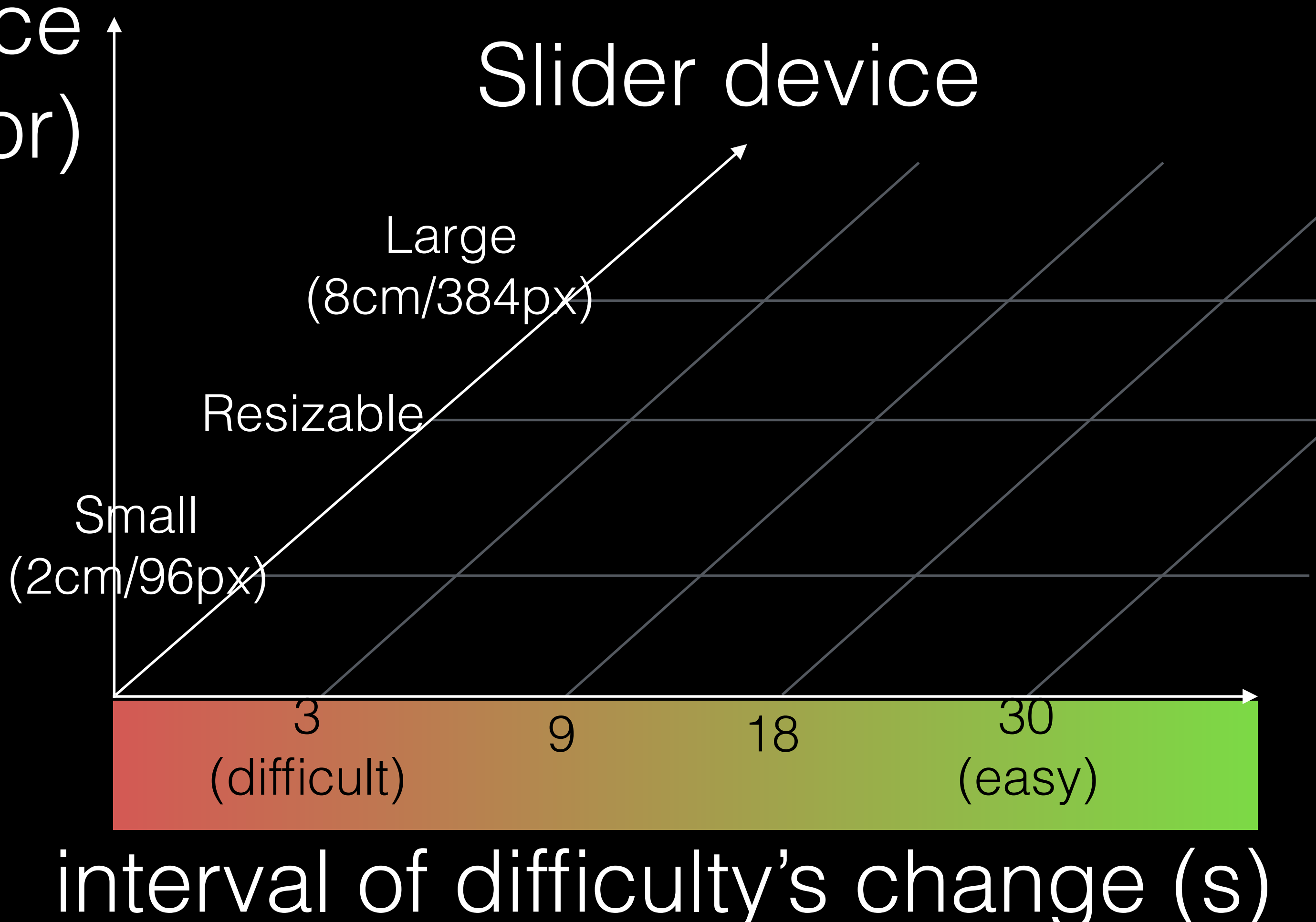
Drawback of resizing: Experiment 2

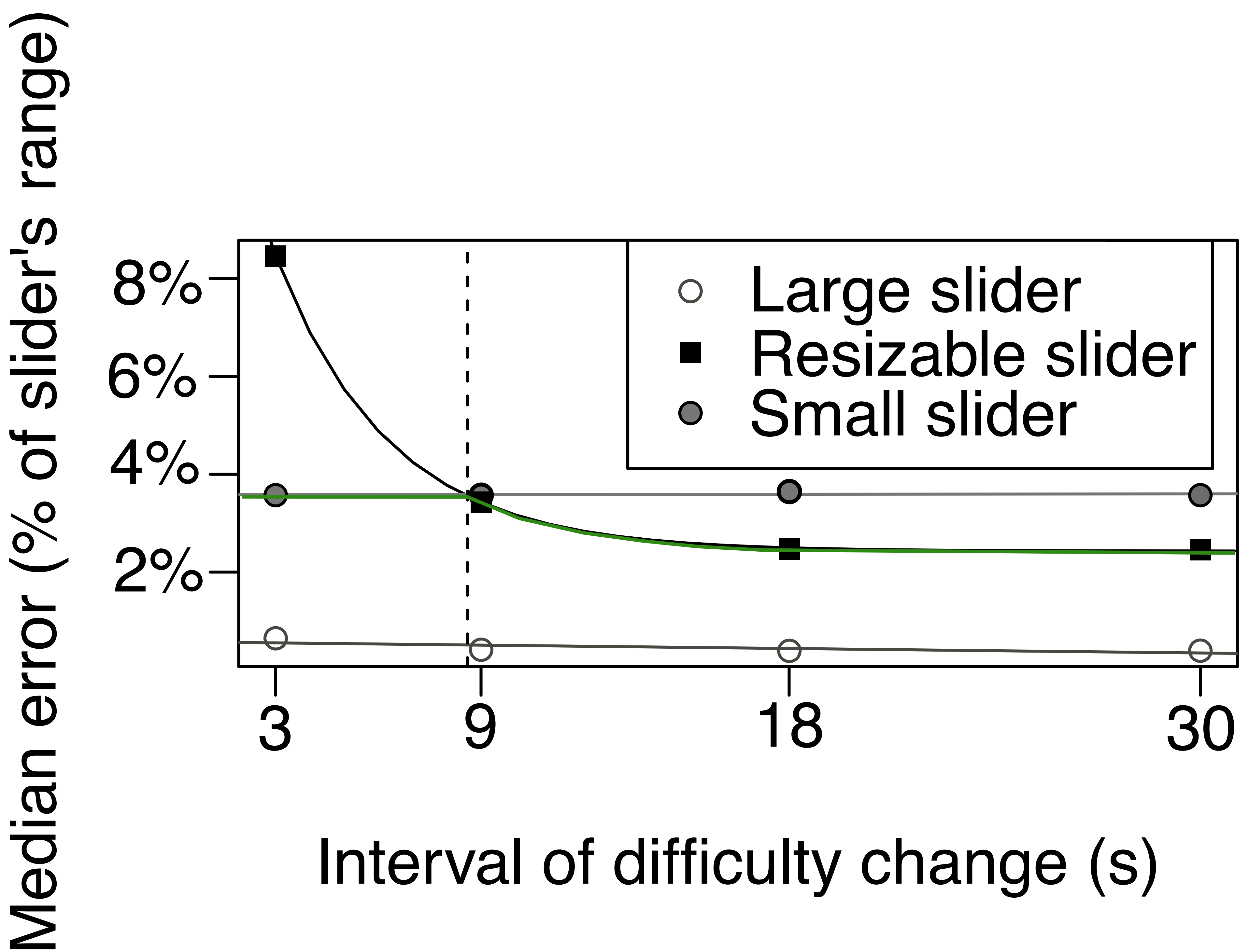


Need to measure
the limit of usability



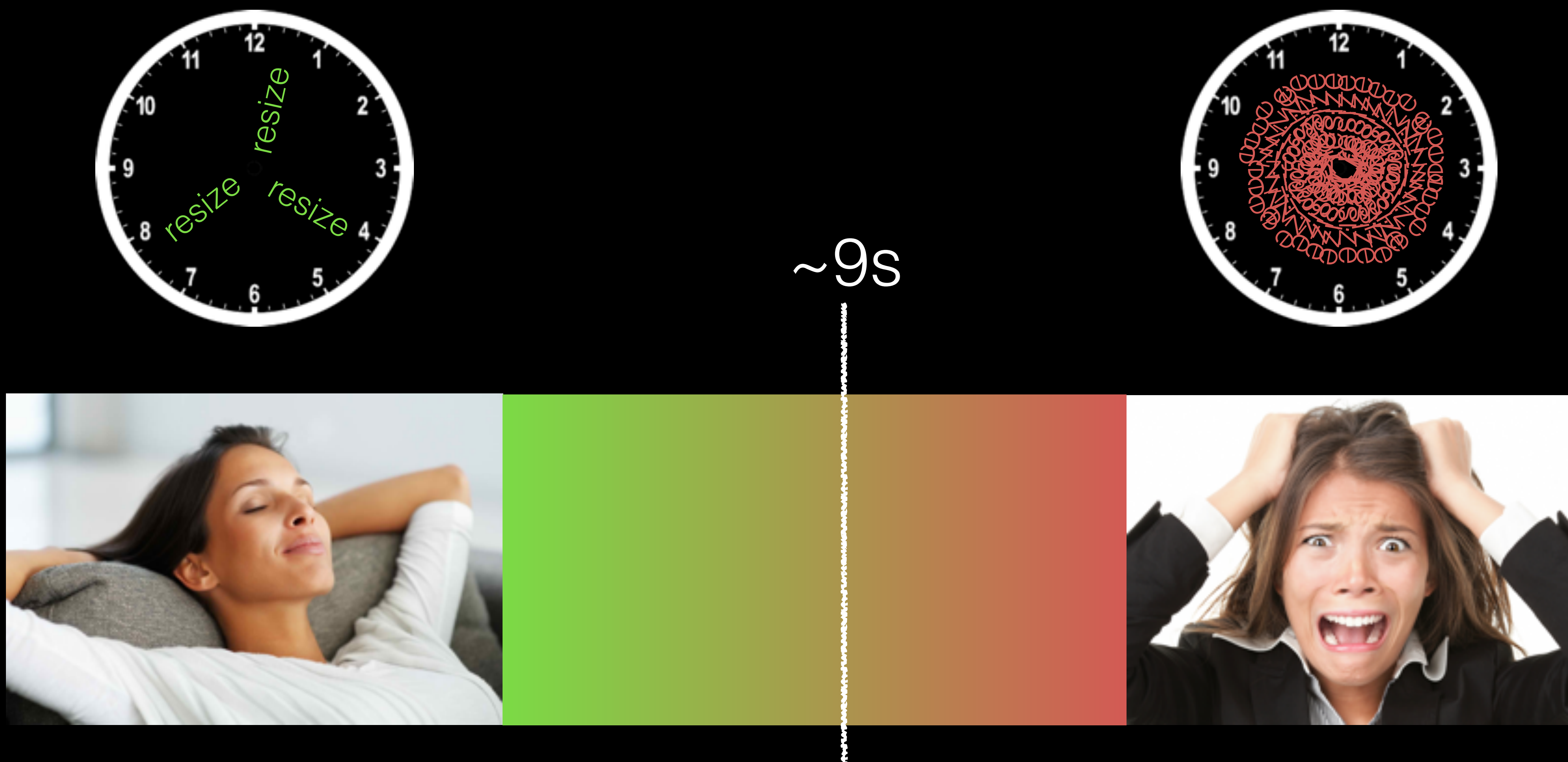
Drawback of resizing: Experiment





if no room available, resize only if less often than every ~9 seconds

Resizing brings benefits
If less often than every ~9 seconds



Future of Tangible Interaction

Flexibility will not be software's monopoly
and will reach Tangibles

Radical Atoms & Perfect Red

Claytronics

Future of Tangible Interaction

Focus group