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?

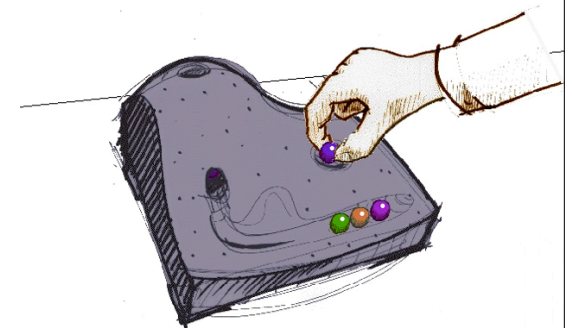 - What are their limitations? + Research areas

- 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
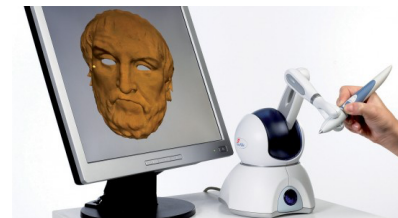
Tangible User Interfaces: What are they?

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
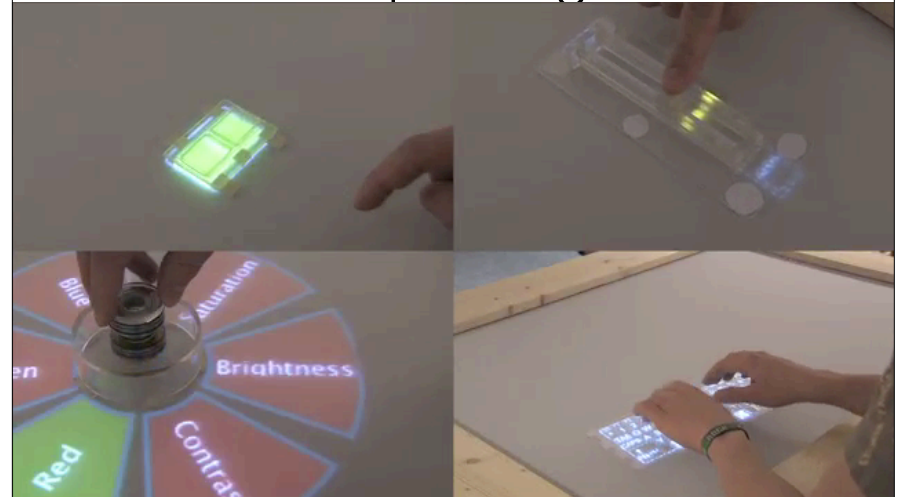
Tangible User Interfaces: What are they?

Internet of Things
TUI not necessarily connected to Internet
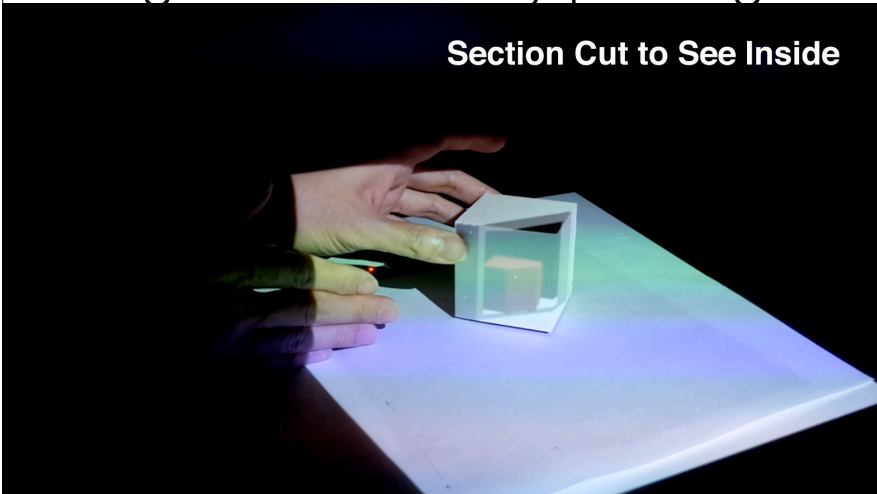If so, can be through a computer

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Spread: GUI paradigm

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Spread: Augmented Reality paradigm
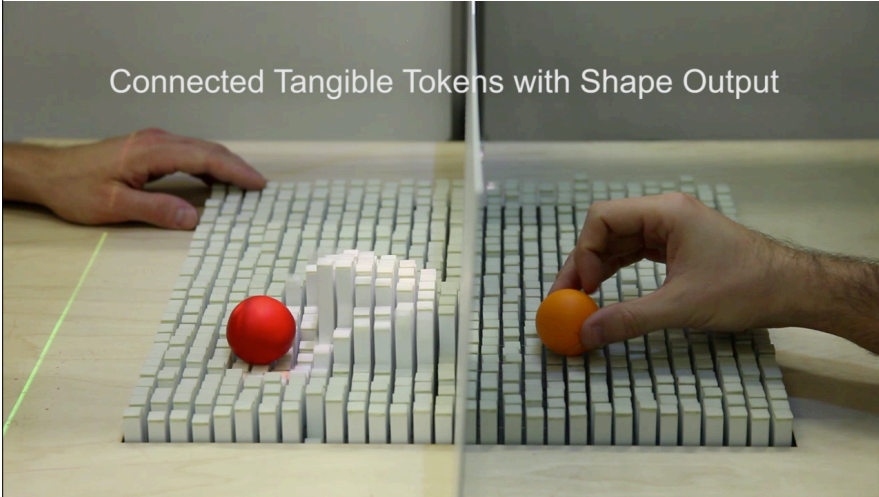

Section Cut to See Inside

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Spread: visualisation tasks

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Spread:
Remote collaboration tasks

Connected Tangible Tokens with Shape Output

What is their story?
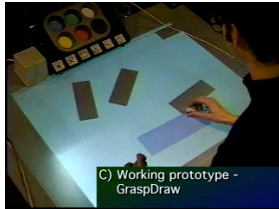
Manipulation of tangible tools has always been here...
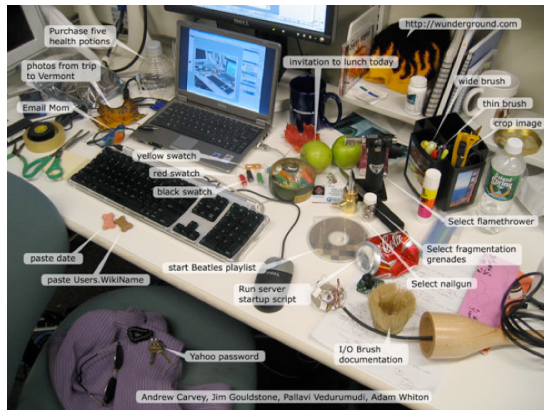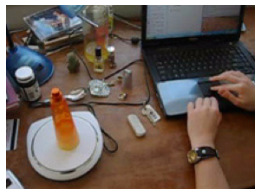
... and is still here

Seminal papers

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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

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Example of
Tangible User Interfaces

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

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Example of
Tangible User Interfaces

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

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Example of
Tangible User Interfaces
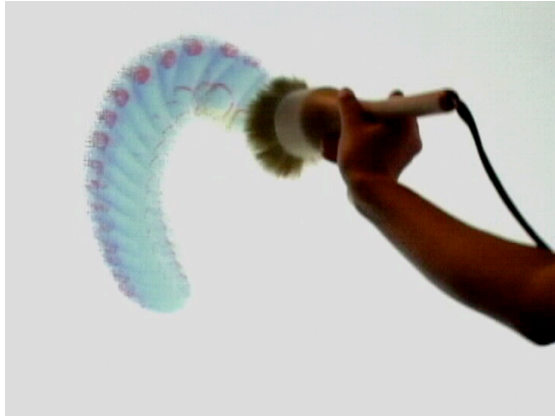
I/O Brush

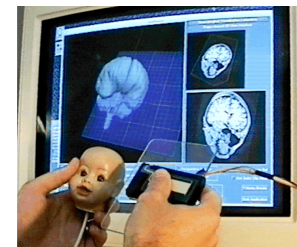# Tangible User Interfaces
What are they good for?

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

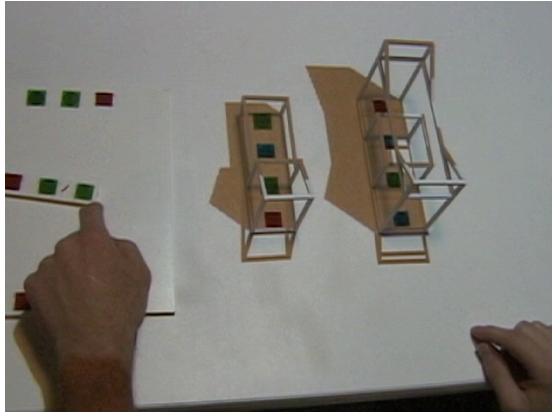Object (prop) to interact at a distance with GUI
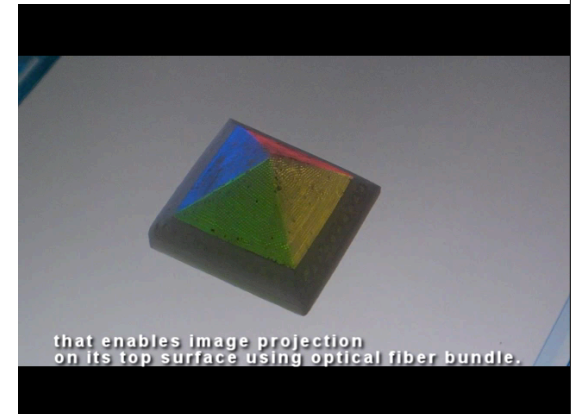
Embodied interaction

Tangible and overlaid projection

Example: URP

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Embodied interaction

Rear-projection and optical fibers

that enables image projection
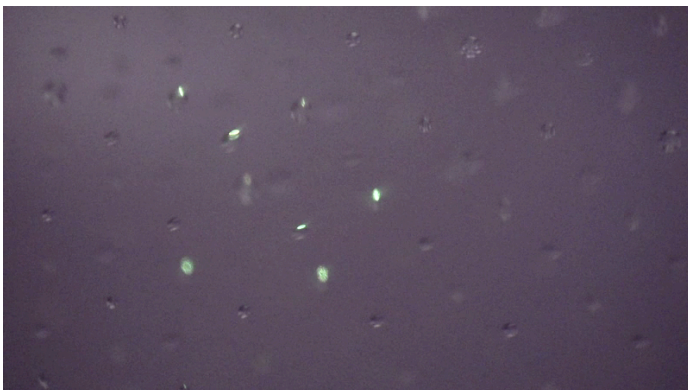on its top surface using optical fiber bundle.

Example: Ficon

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Embodied interaction

Printed Optics

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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

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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
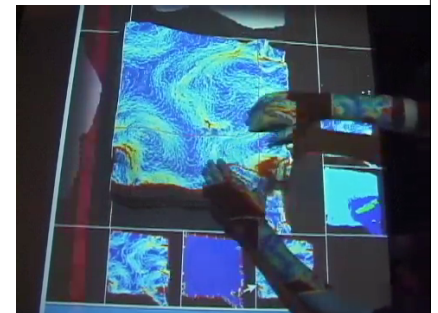
- **Noun & Verb** = "<X>-ing an <A> in our system is like <X>-ing something <A>-ish in the real world"

  - 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
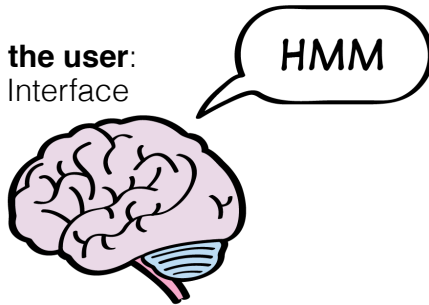
  - E.g., Illuminating Clay

Tangible User Interfaces
What are they good for?

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

  HMM

- **Performance**:
  passive haptic feedback

Methodological break
User studies

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

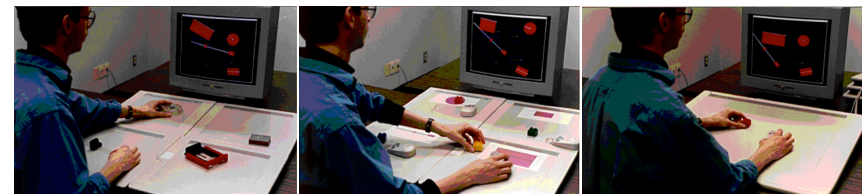- Time-multiplexed vs. Space-multiplexed input: inter-device transaction phases

GUI	TUI
Acquire physical device	Acquire physical device
Acquire logical device	
Manipulate logical 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
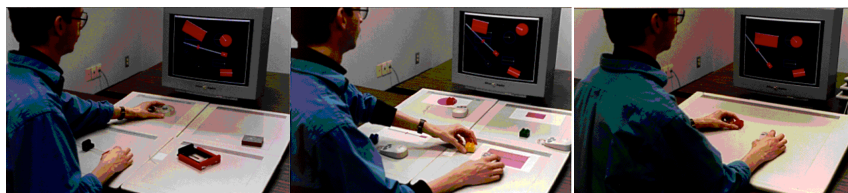- Ruler: position, rotation and scale

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?

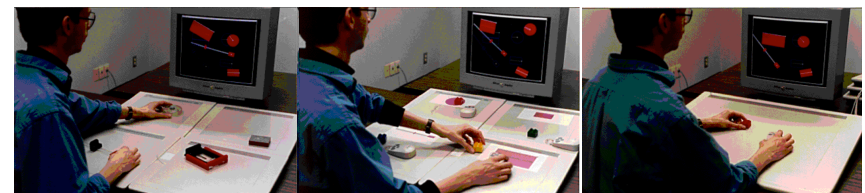Space-multiplexed Specialized   Space-multiplexed Generic   Time-multiplexed

Tangible User Interfaces: Benefit over GUI

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

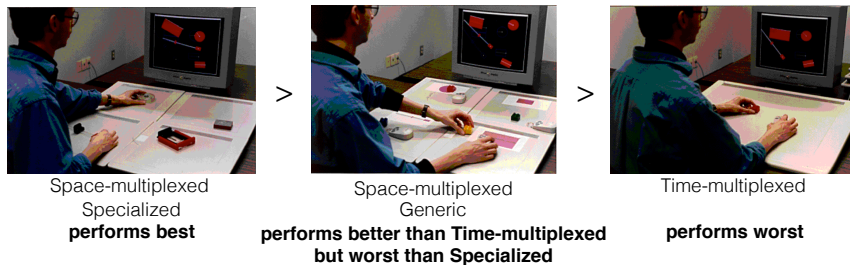Is the **specialized** input useful?

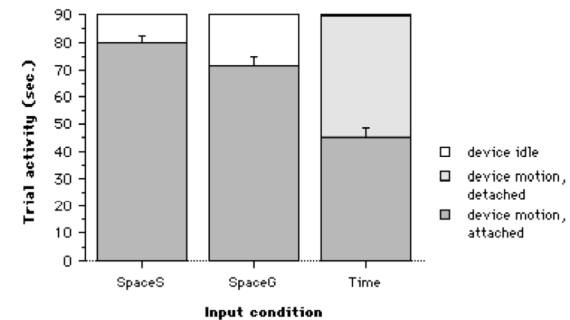Space-multiplexed Specialized   Space-multiplexed Generic   Time-multiplexed

Tangible User Interfaces: Benefit over GUI

Space-multiplexed
Specialized
performs best

>

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

>

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)
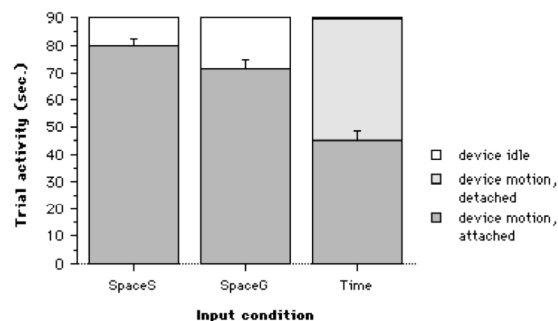
66

Tangible User Interfaces: Benefit over GUI

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Tangible User Interfaces: Benefit over GUI

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

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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

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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
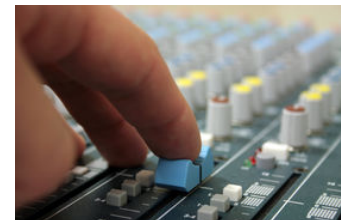
What about multitouch input?

also space-multiplexed

Tangible User Interfaces:
Benefit over multitouch

Two experiments

Acquisition   Manipulation
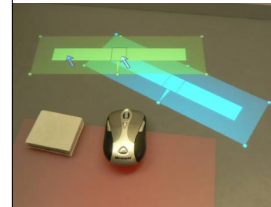
Tangible User Interfaces:
Benefit over multitouch

Manipulation

Assumes users already acquired
the control widget

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Tangible User Interfaces:
Benefit over multitouch

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

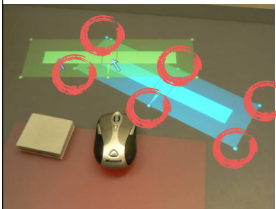Mouse+Puck   Multitouch   Tangible
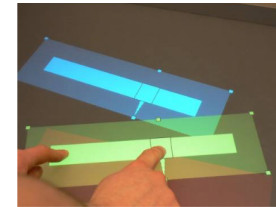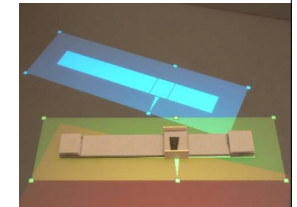
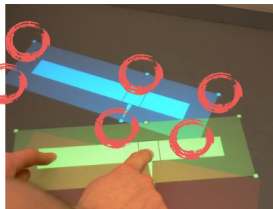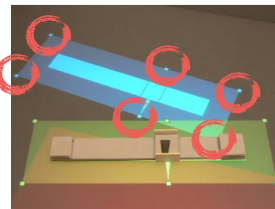(all conditions sensed through multitouch table)

75

Tangible User Interfaces:
Benefit over multitouch

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

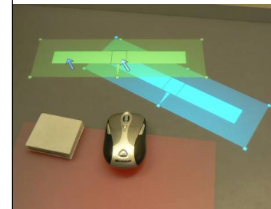±5px

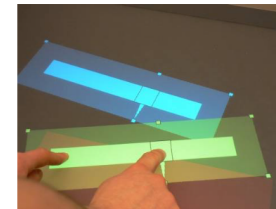Mouse+Puck   Multitouch   Tangible

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Tangible User Interfaces:
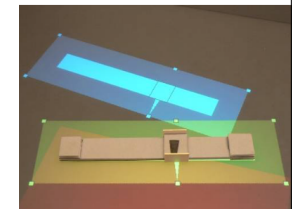## Benefit over multitouch

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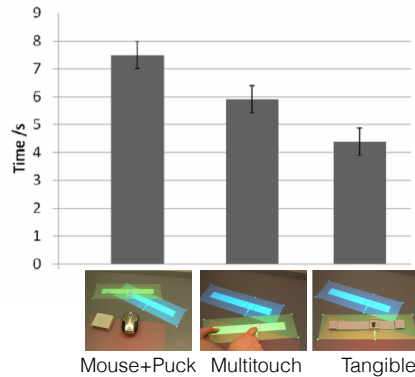Subjective ease of use

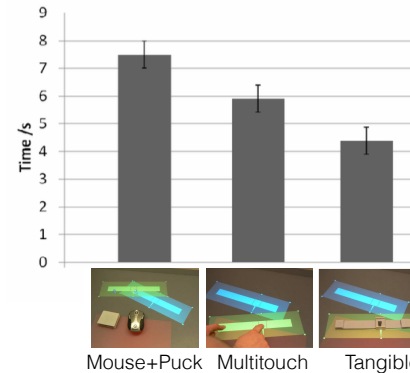Mouse+Puck   Multitouch   Tangible

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Tangible User Interfaces: Benefit over multitouch

Mouse+Puck Multitouch Tangible

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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 »

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Tangible User Interfaces: Benefit over multitouch

Manipulation

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Tangible User Interfaces: Benefit over multitouch

Two experiments

Acquisition

Manipulation
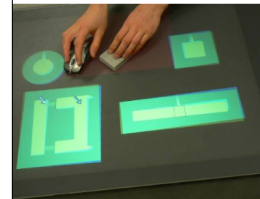

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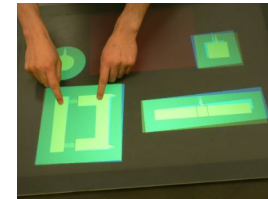# Tangible User Interfaces: Benefit over multitouch

Acquisition

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Tangible User Interfaces: Benefit over multitouch
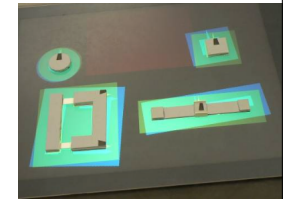
Task: match position+orientation+cursor of blue objects
manipulating yellow objects
at all times

Mouse+Puck   Multitouch   Tangible

(all conditions sensed through multitouch table)

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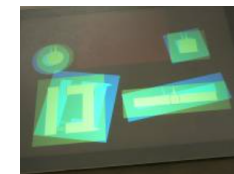# Tangible User Interfaces: Benefit over multitouch

time

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

⇒ move between widgets ⇒ many (re)acquisitions

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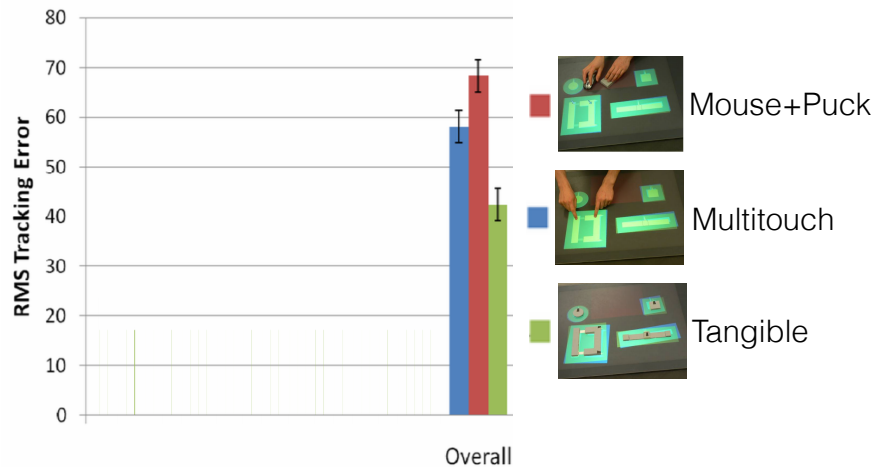# Tangible User Interfaces: Benefit over multitouch

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

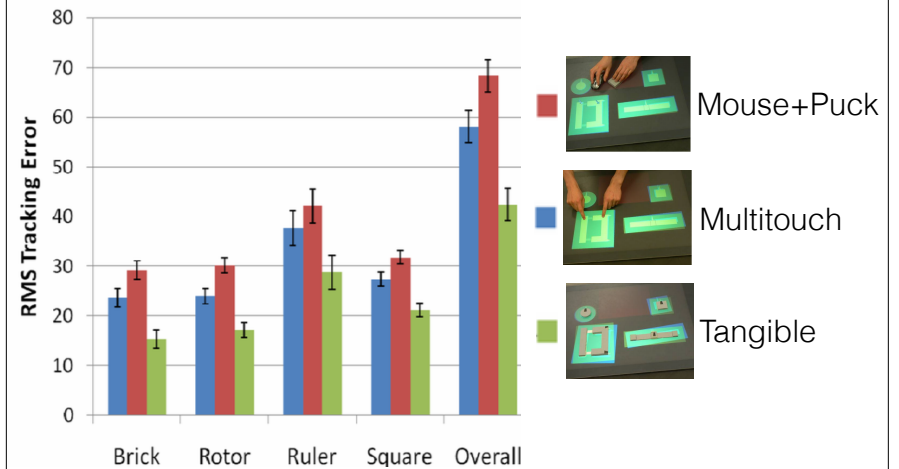+ subjective preference, confort and ease of use
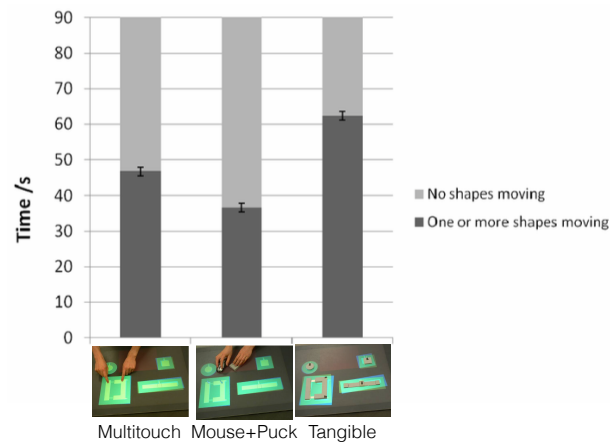
85

Tangible User Interfaces: Benefit over multitouch
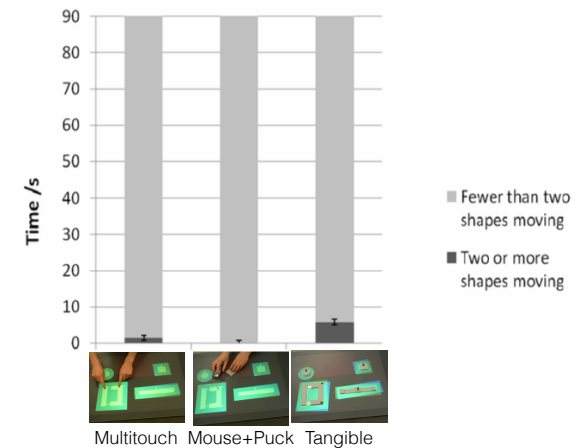

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Tangible User Interfaces: Benefit over multitouch

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Tangible User Interfaces: Benefit over multitouch
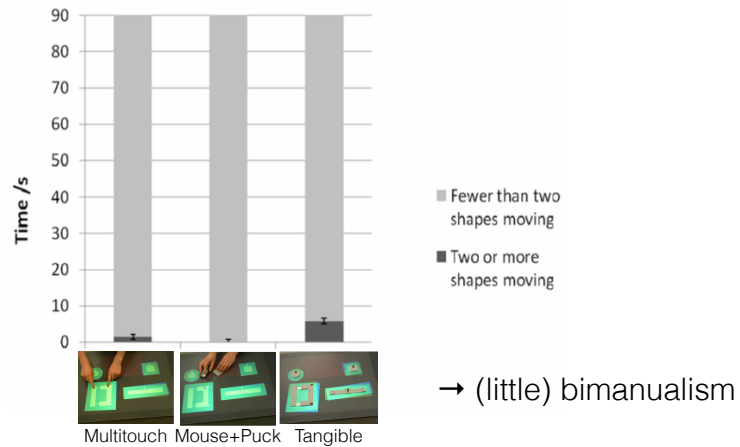

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Tangible User Interfaces: Benefit over multitouch
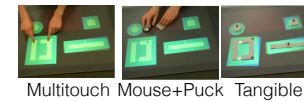

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Tangible User Interfaces:
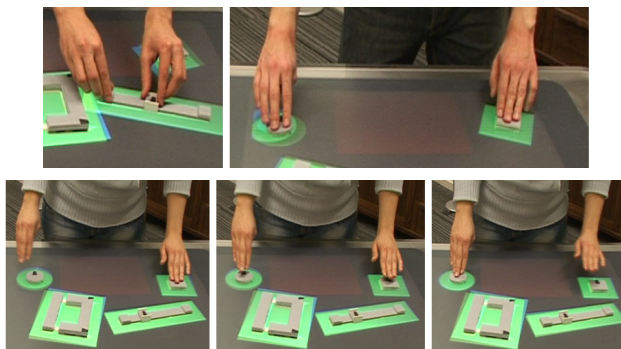## Benefit over multitouch

Multitouch Mouse+Puck Tangible

→ (little) bimanualism

Tangible User Interfaces:
Benefit over multitouch

+ Little difference in preference,
comfort
and ease of use

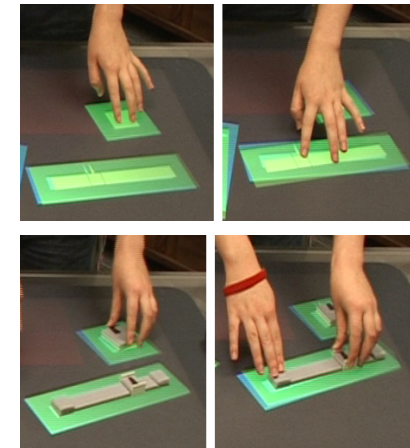

Multitouch Mouse+Puck Tangible

Tangible User Interfaces:
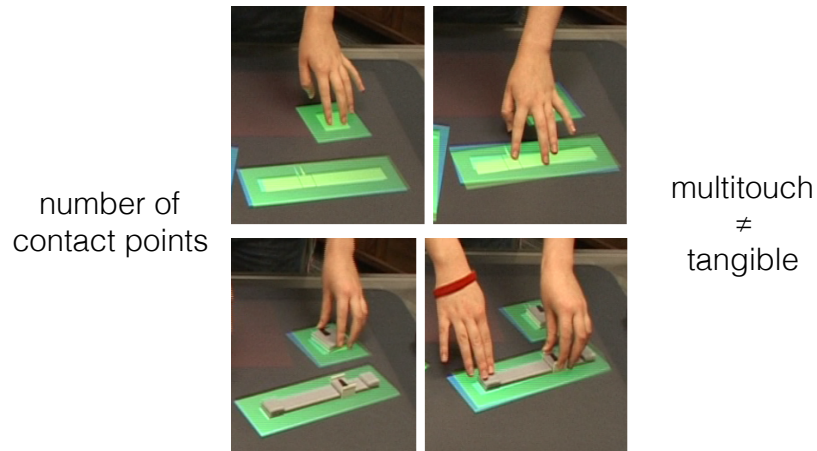## Benefit over multitouch

Same pattern for multitouch and tangible

Tangible User Interfaces:
Benefit over multitouch
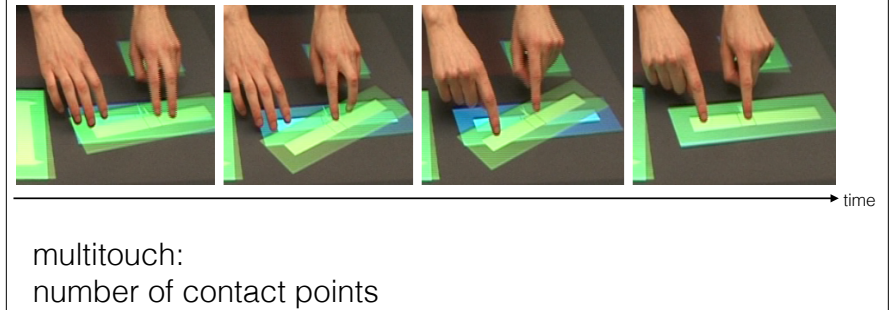

multitouch
≠
tangible

Tangible User Interfaces: Benefit over multitouch
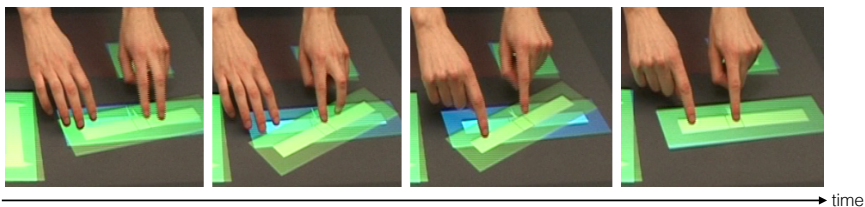

number of contact points

multitouch
≠
tangible

Tangible User Interfaces: Benefit over multitouch

time

multitouch:
number of contact points

Tangible User Interfaces: Benefit over multitouch

time

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

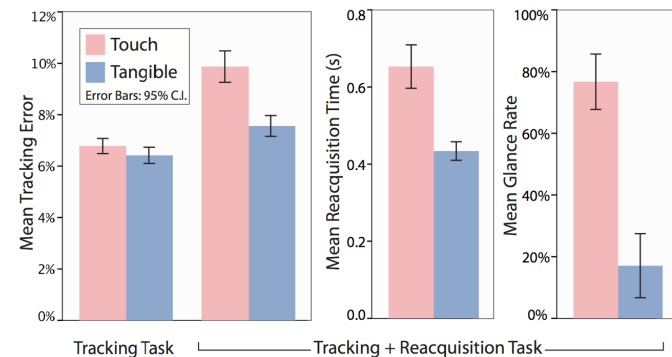# Tangible User Interfaces: Benefit for distant interaction

- Techniques: Touch vs. Tangible slider

- Tasks: Tracking vs. Tracking + additional tapping

Tangible User Interfaces: Benefit for distant interaction
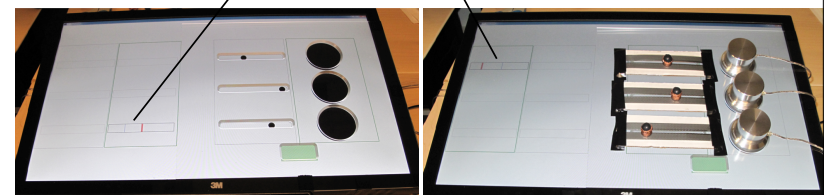
- Comparing touch and tangible interaction

Tangible User Interfaces: What are they good for?

Several experiments demonstrated their benefits

Tangible User Interfaces: Benefit over touch and overlay
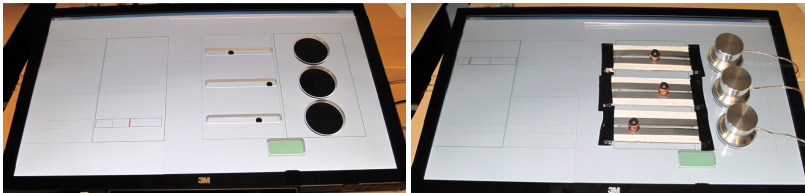
Tasks: set horizontal position of cursor

Slide 102

Tangible User Interfaces:
Benefit over touch and overlay

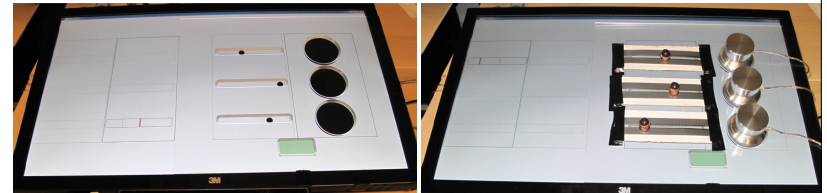Tasks: set horizontal position of cursor

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

Slide 103

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)			

Slide 104

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)			

Slide 105

Tangible User Interfaces:
Benefit over touch and overlay

Task 1: acquisition and movement
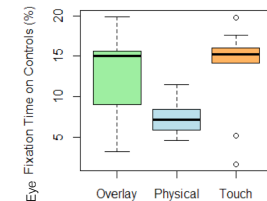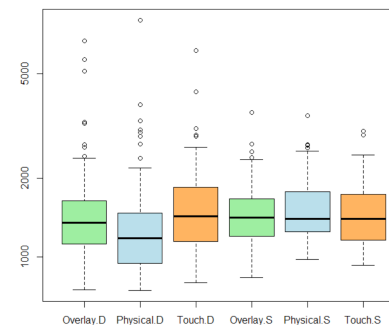
Tangible User Interfaces: Benefit over touch and overlay
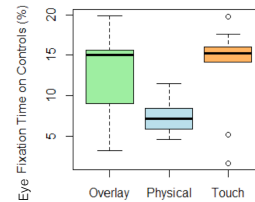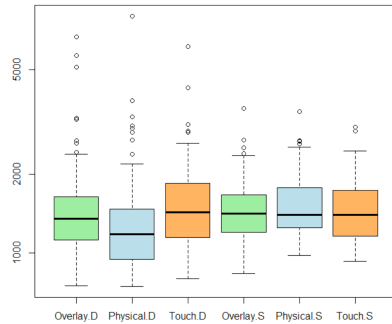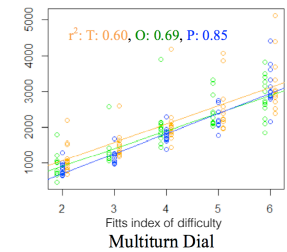
Task 1: acquisition and movement

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

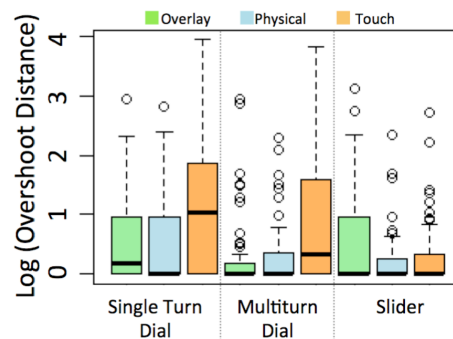Task 2: Repetitive movement

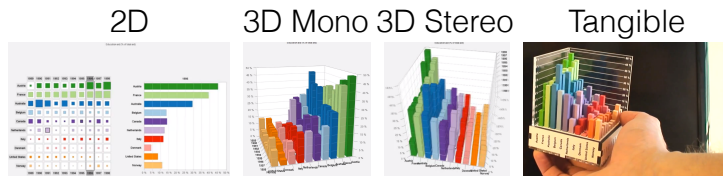# Tangible User Interfaces: Benefit over touch and overlay

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?
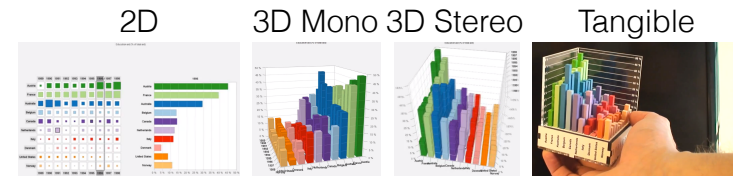
2D 3D Mono 3D Stereo Tangible
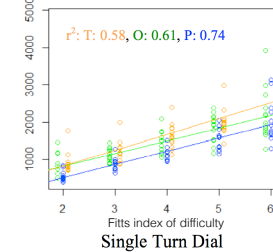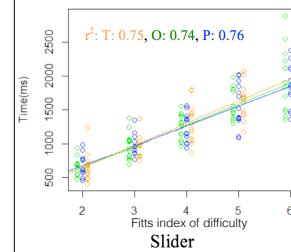
Tasks

- 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?
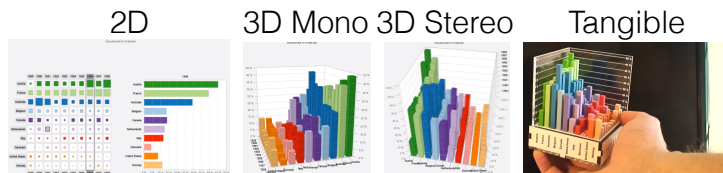
2D 3D Mono 3D Stereo Tangible

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

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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

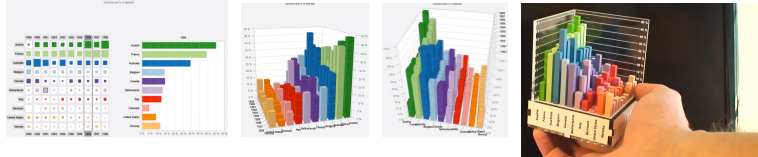---

Proprioception

Definition:

- Perception of our own body

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

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Tangible User Interfaces: What are they good for?
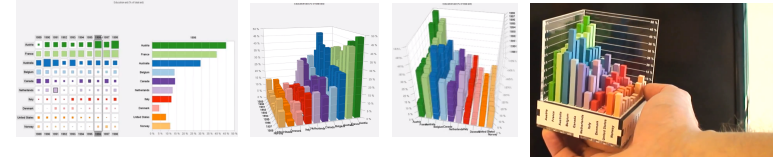
2D   3D Mono 3D Stereo Tangible

Among possible explanation: Direct rotation

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

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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

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Tangible User Interfaces: What are they good for?

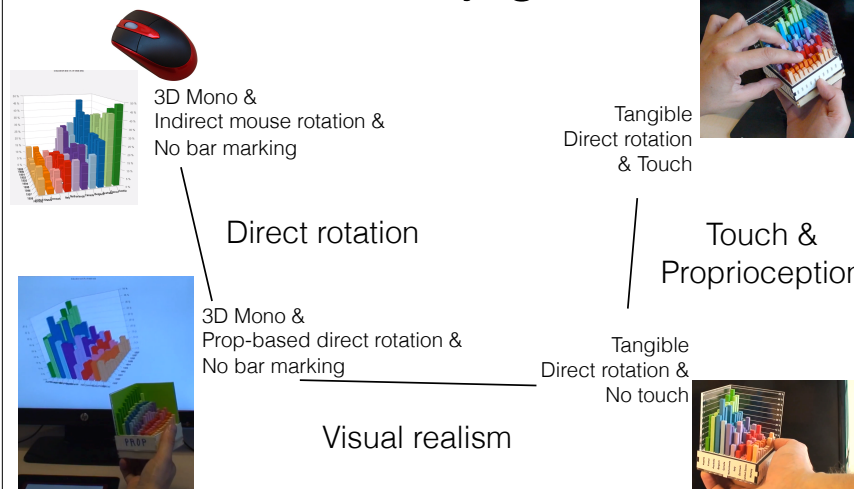2D   3D Mono 3D Stereo Tangible
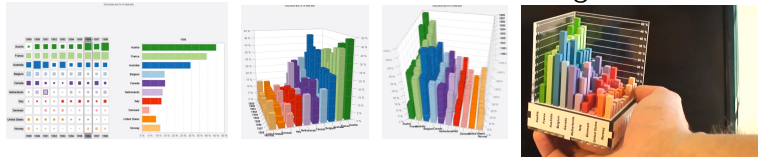
Impact of all possible explanations?

- Touch & Proprioception?

- Direct rotation?

- Visual Realism?

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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

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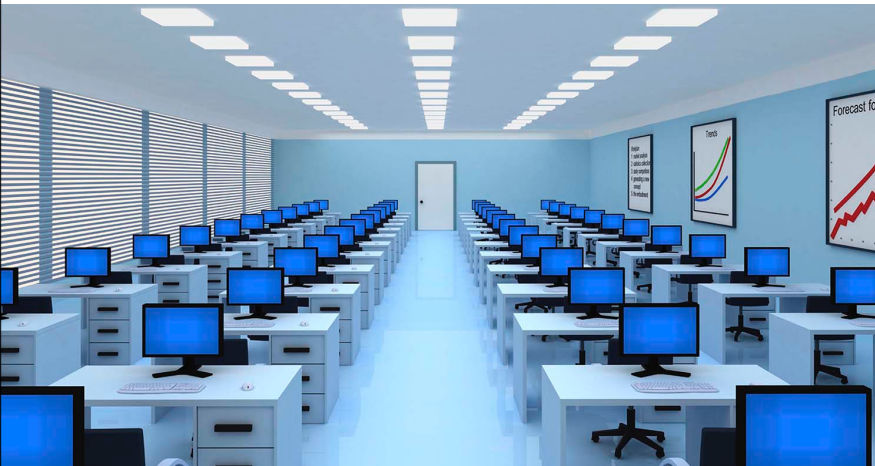## Tangibles User Interfaces: What are they good for?

- 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?