

Interaction tactile multi-points et gestuelle

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ressources: <http://malacria.com/teachings/>

Diapositives adaptées de Géry Casiez et Gilles Bailly



CS Education Week

Recognizing the Transformative Role of Computing

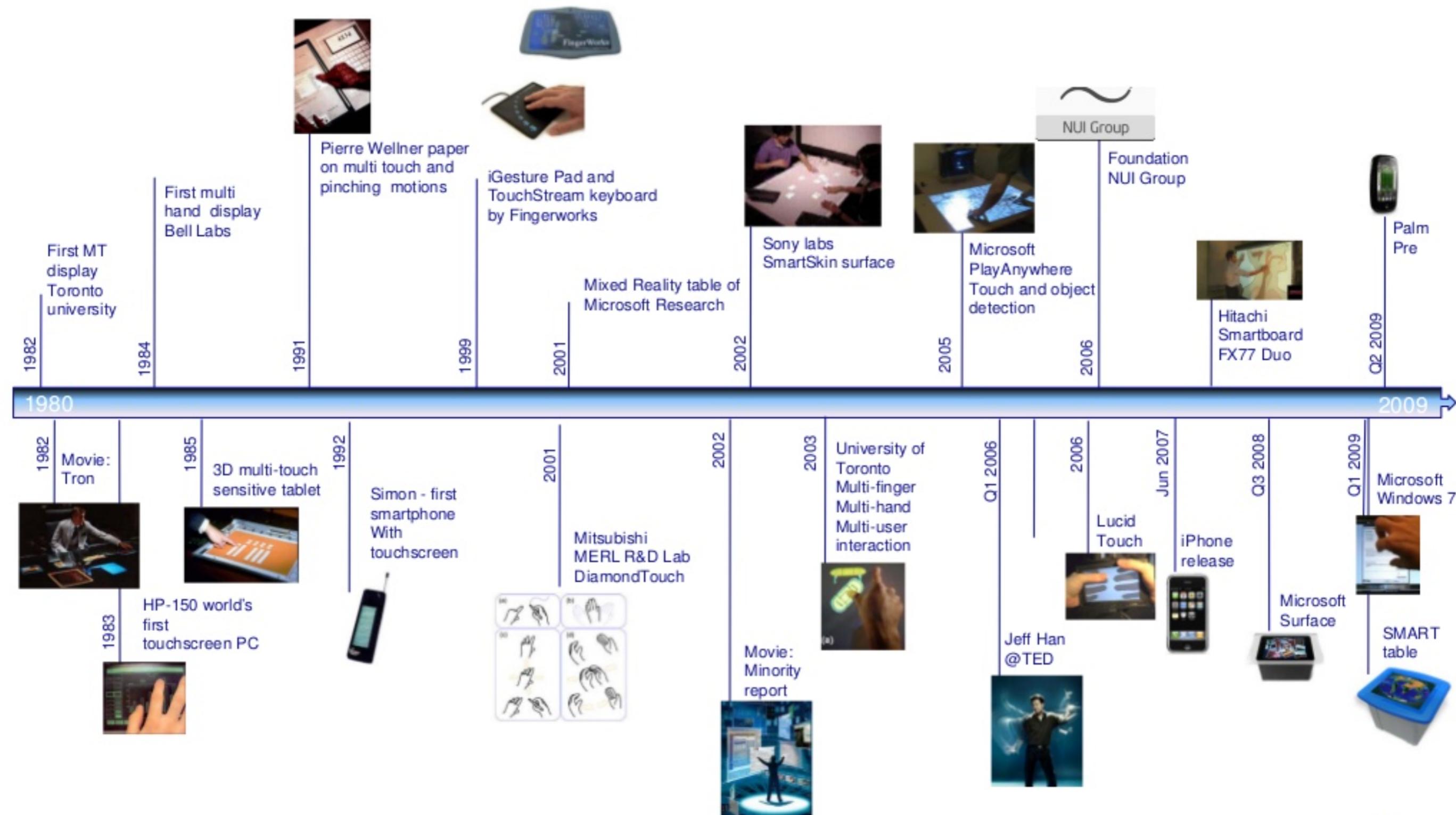
Certified Software

A Conversation with Pixar's Ed Catmull

Bayesian Networks

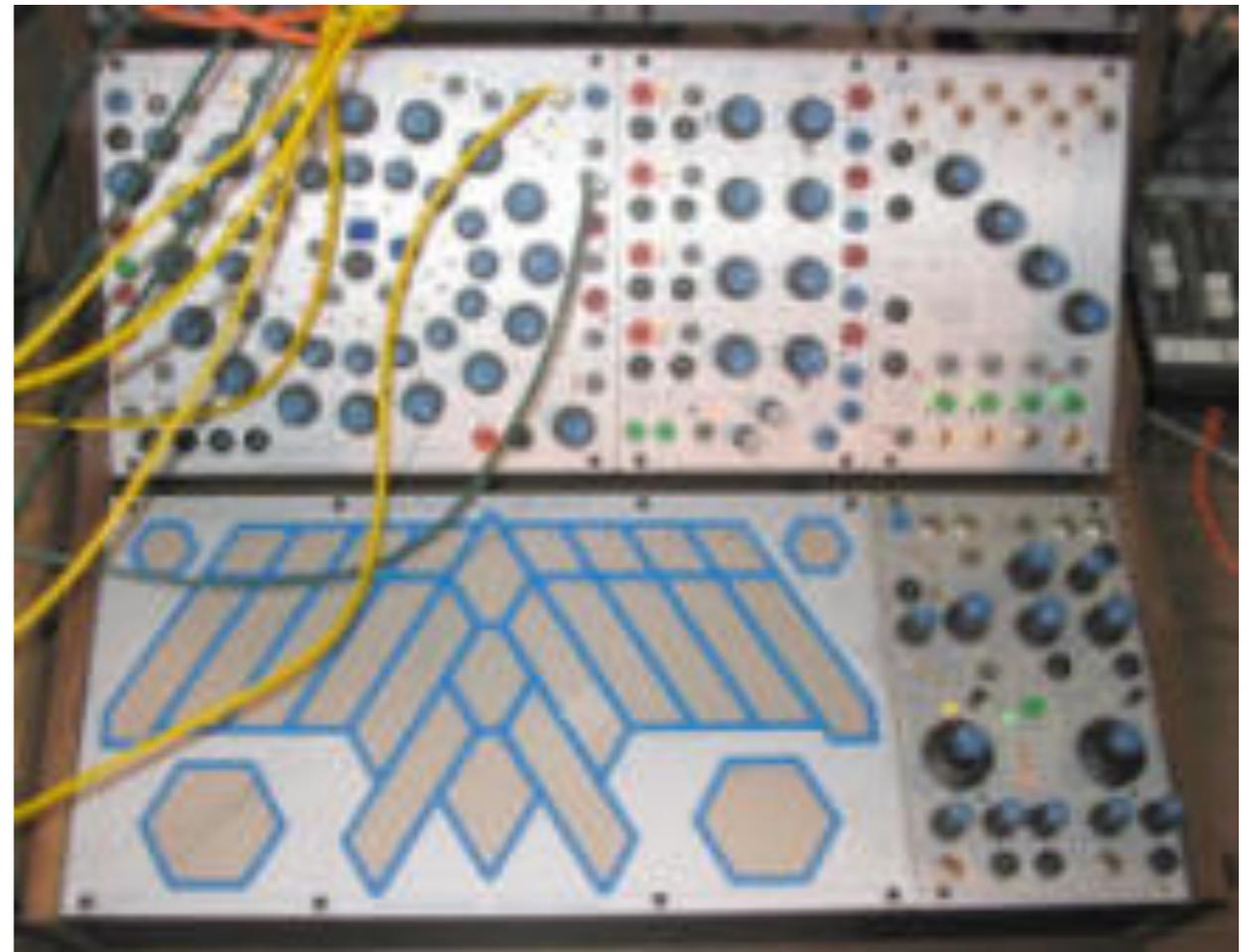
The Theft of Business Innovation

History of Multi-touch interaction





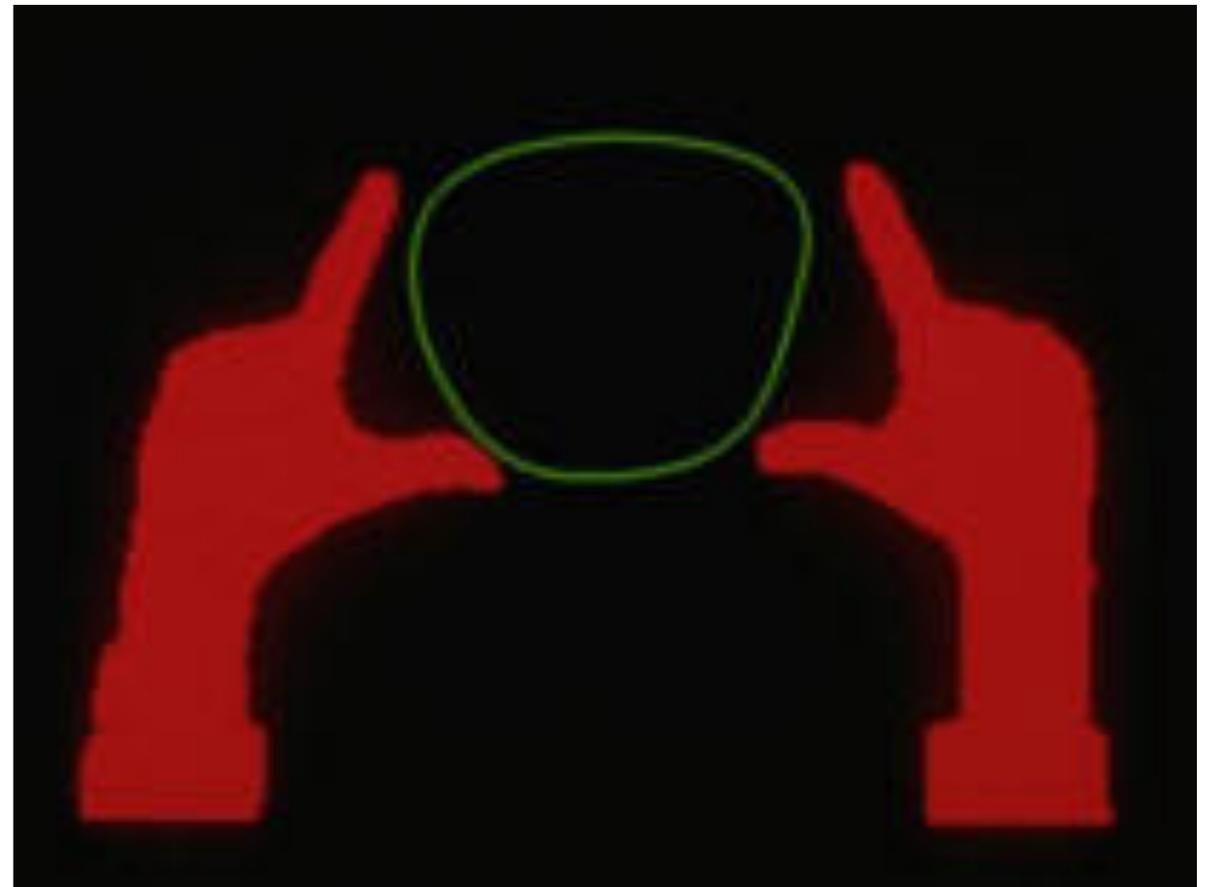
Keyboard



Electronic Touch Sensor

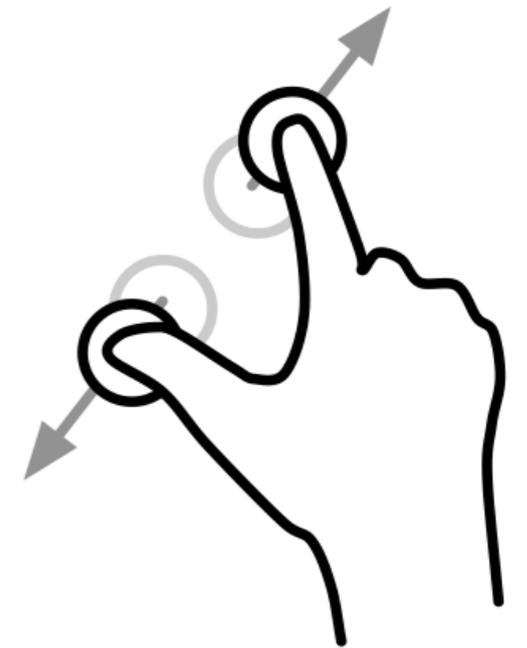
1983

VideoPlace



1985

RST [Krueger et al.]



1985

Multitouch Tablet



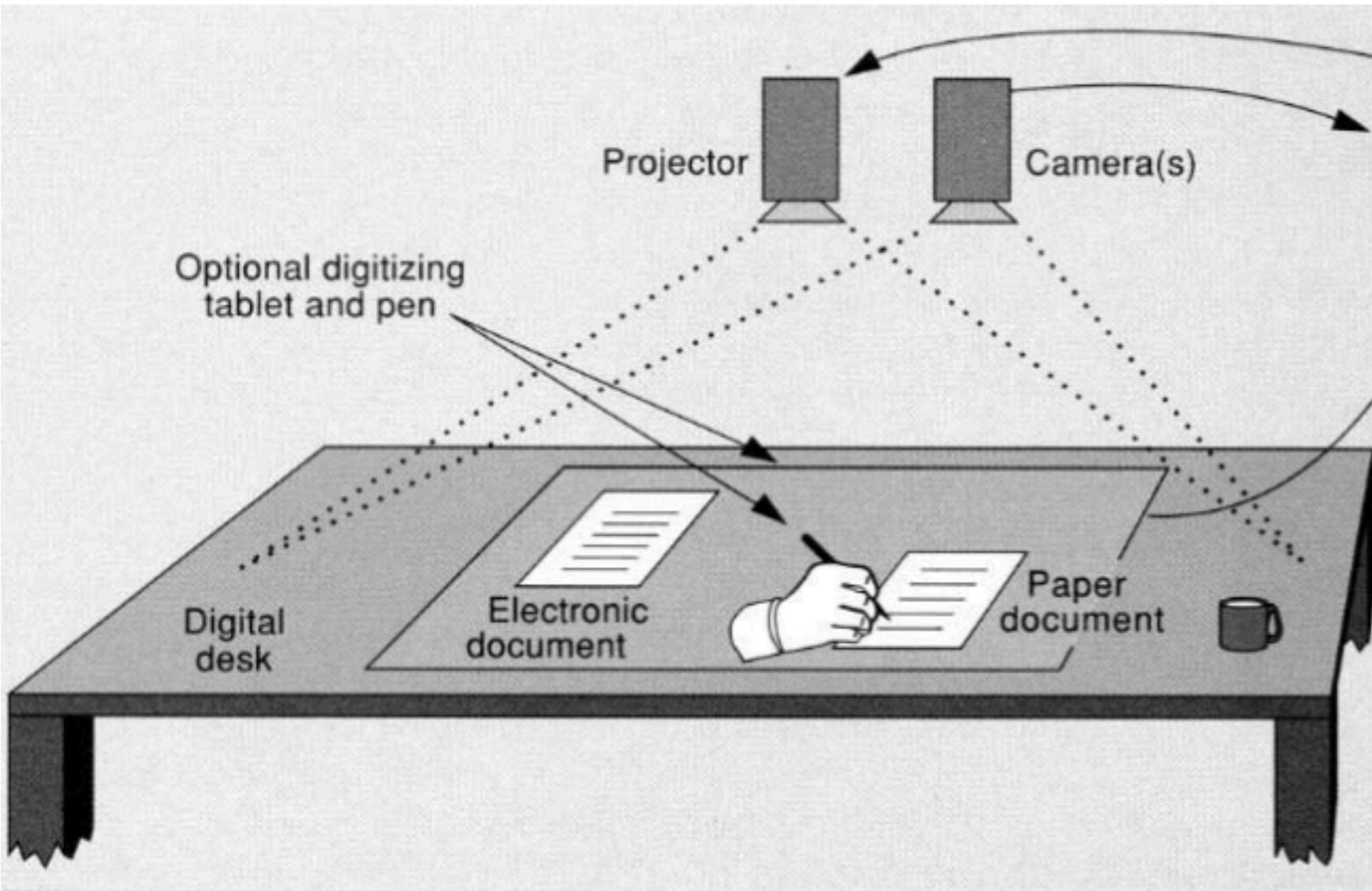
1985

Multitouch Tablet



1991

DigitalDesk



Work 100

00 100 100 100

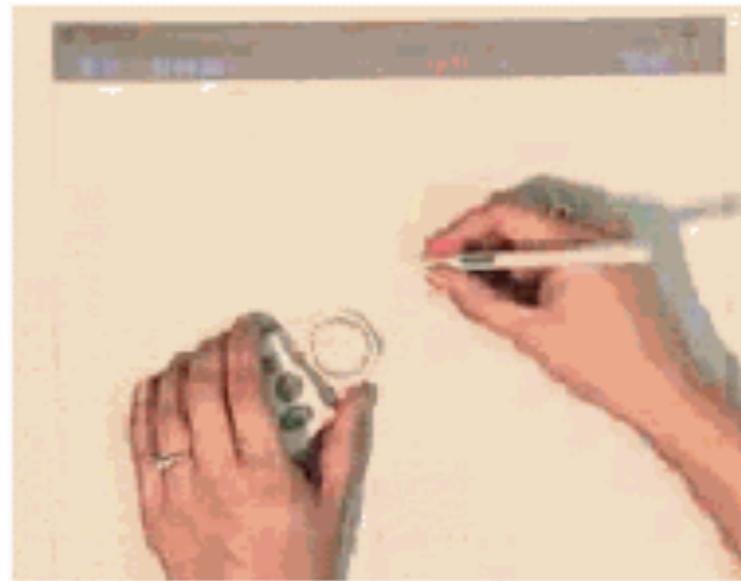


1000000

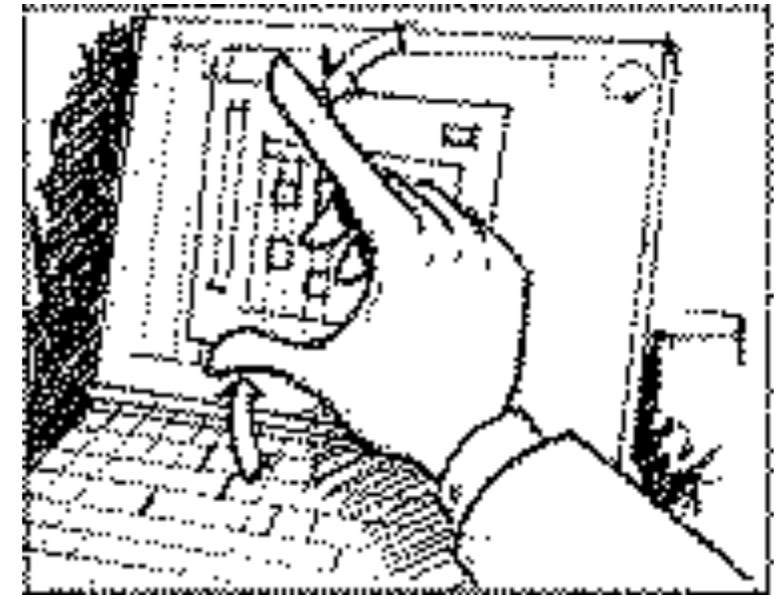
1991



Flip Keyboard



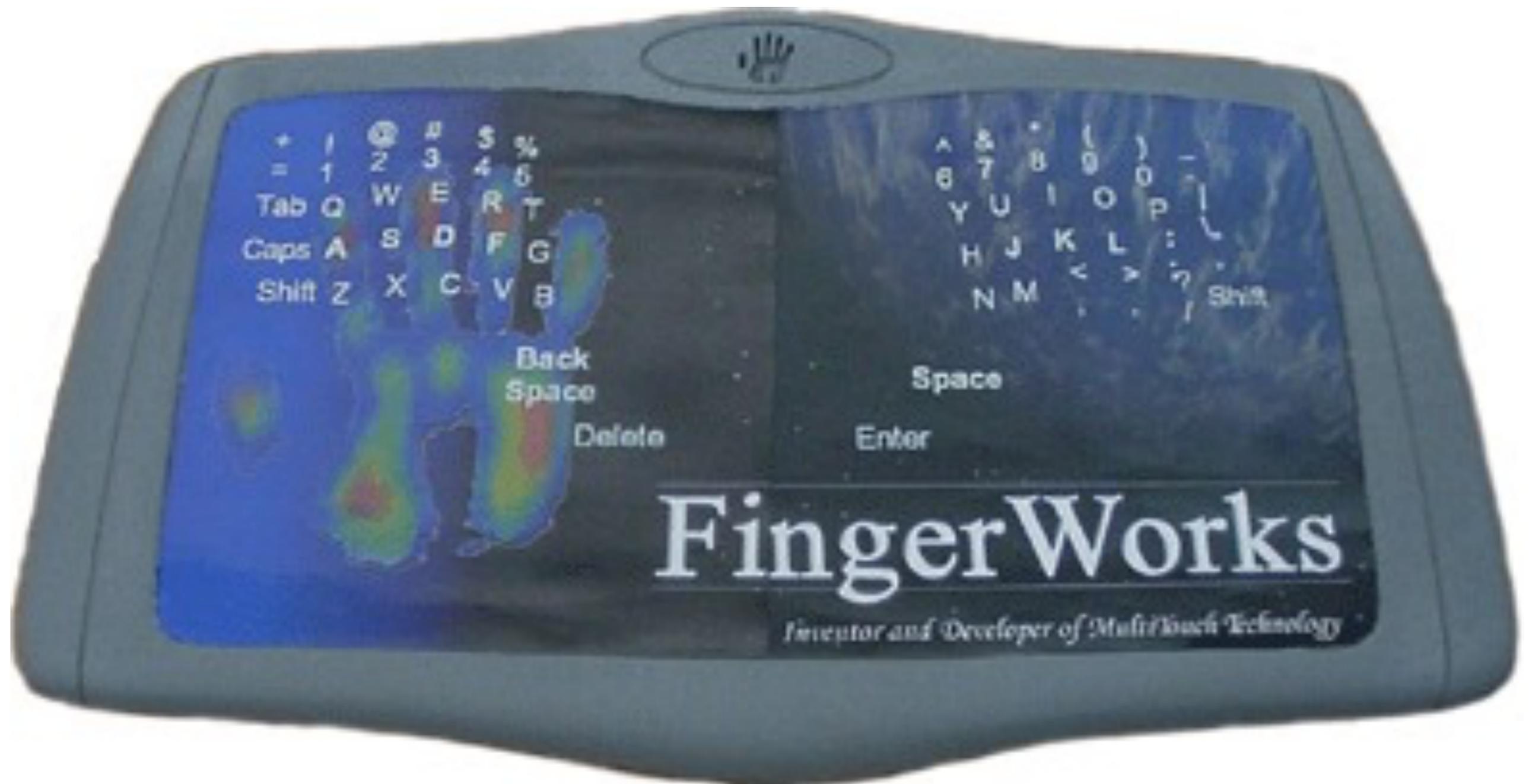
Wacom



Starfire

2001

FingerWorks



2001

Diamond Touch



2002

Smartskin

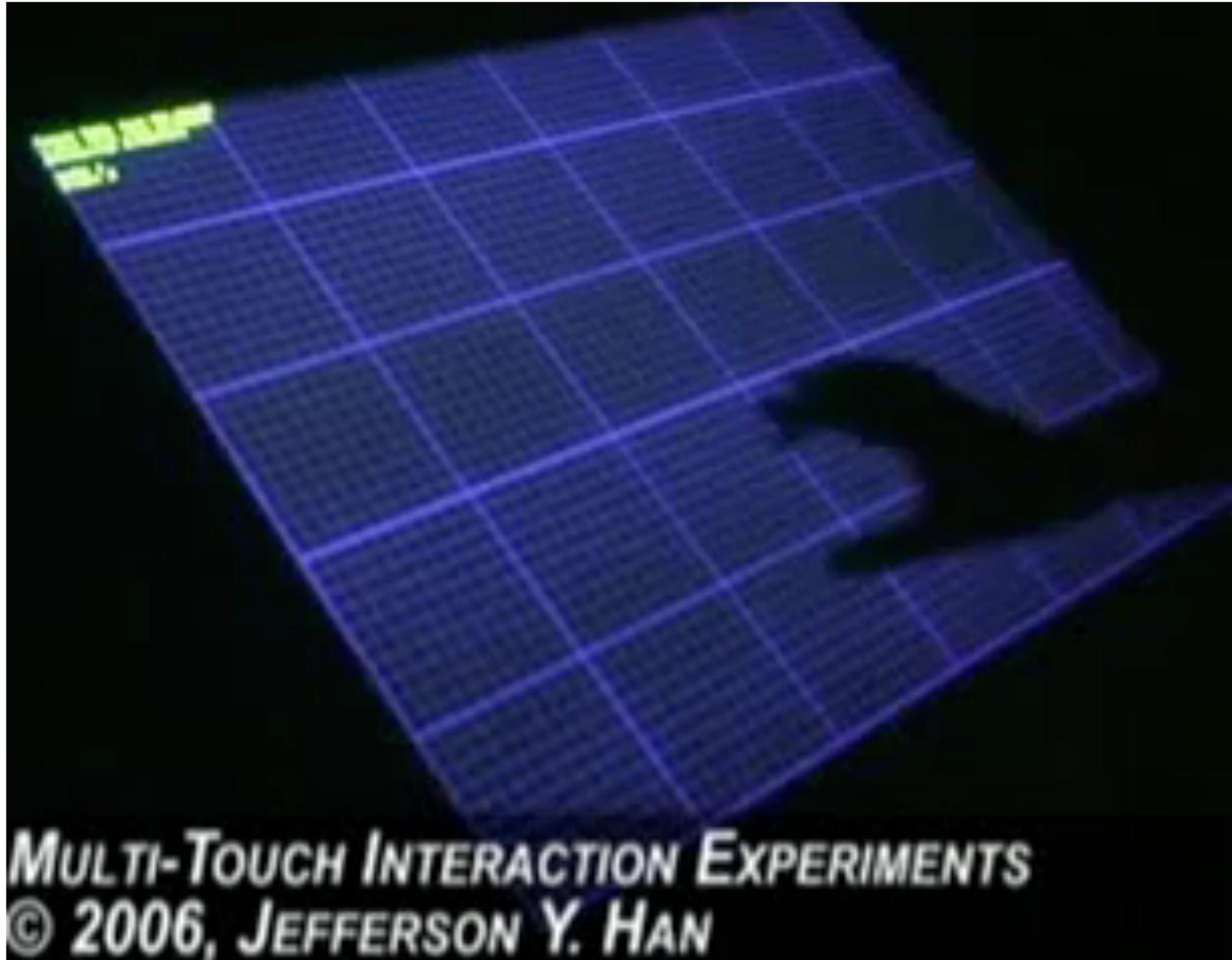


2003

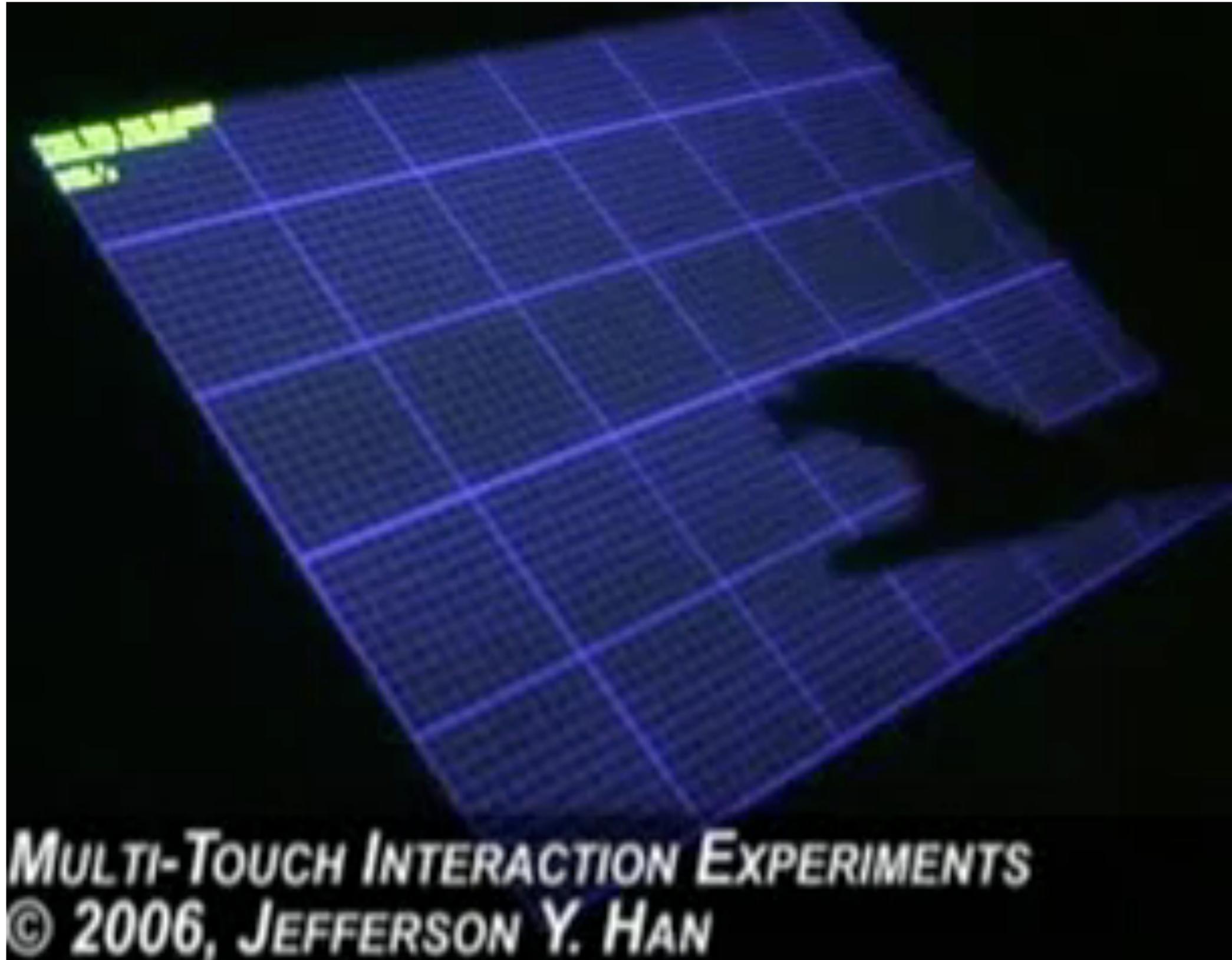
Lemur/Jazz Mutant



2006



2006



2007 *iPhone*



2007

Microsoft Surface



2007
ThinSight



2011

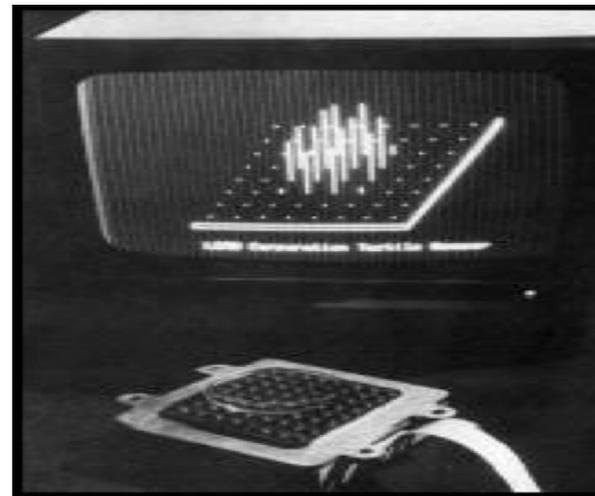
Microsoft Surface 2.0



Technologie



1972
Plato IV



1981



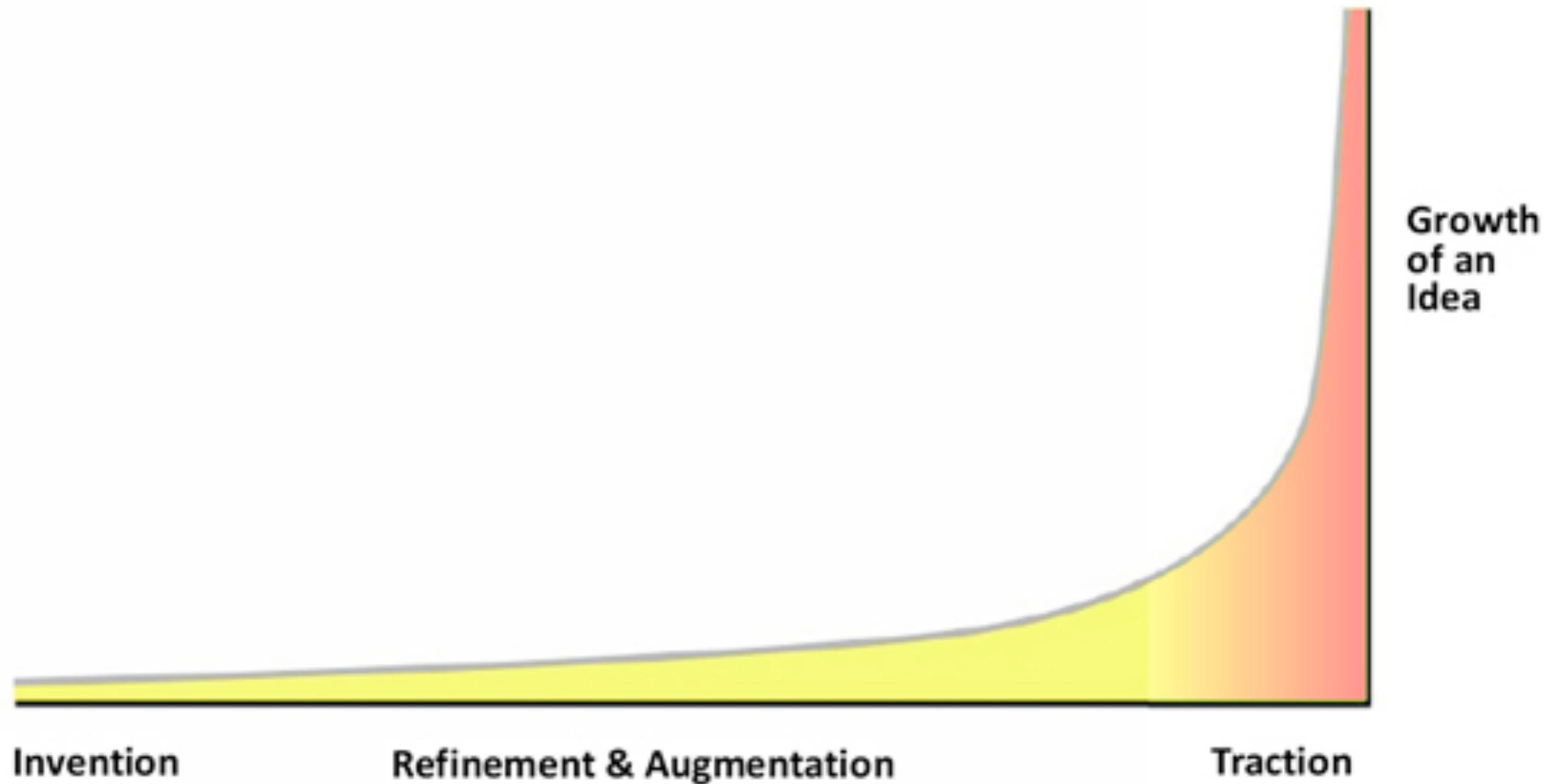
2007
iPhone



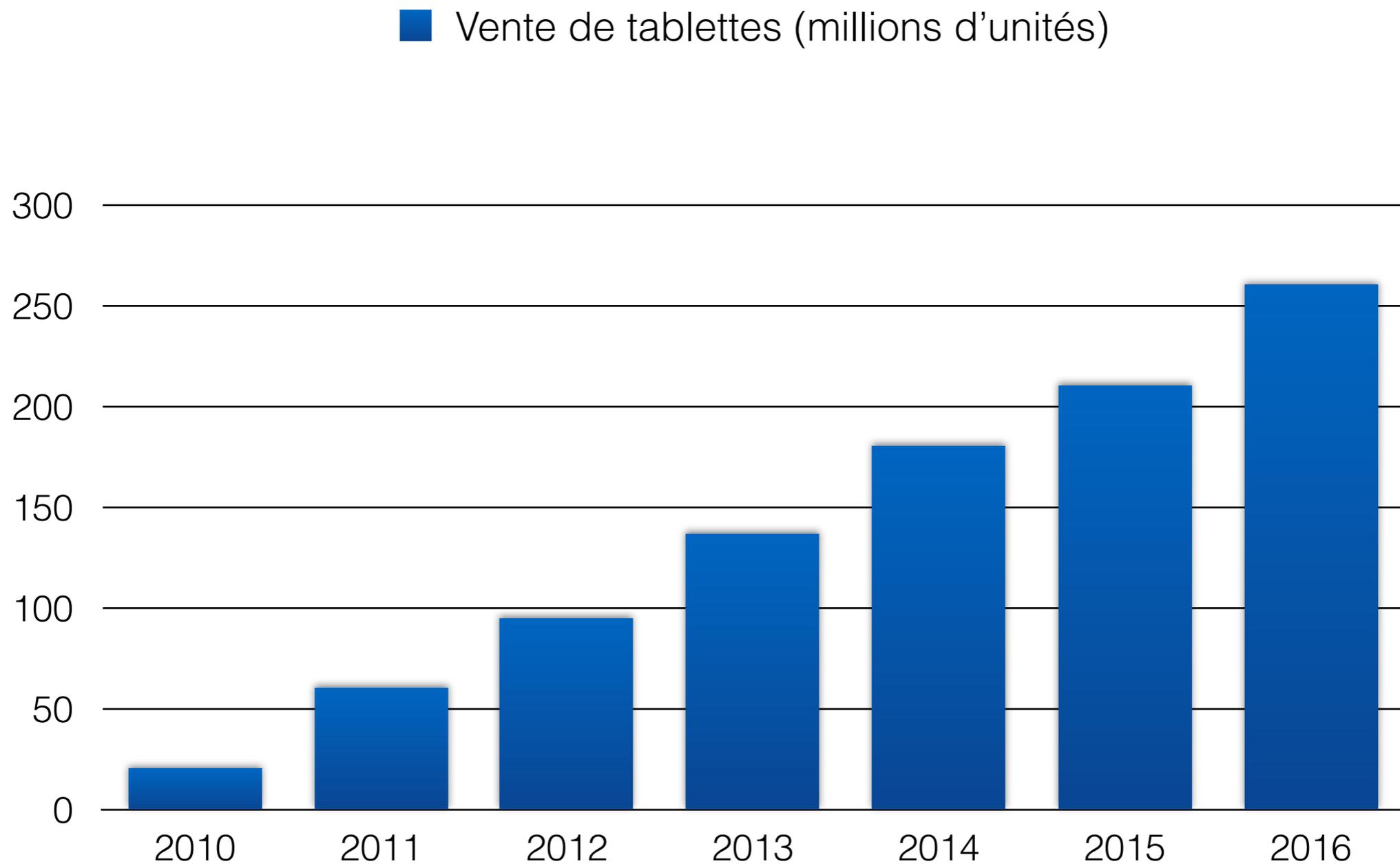
2010
iPad

The long nose of innovation

Bill Buxton

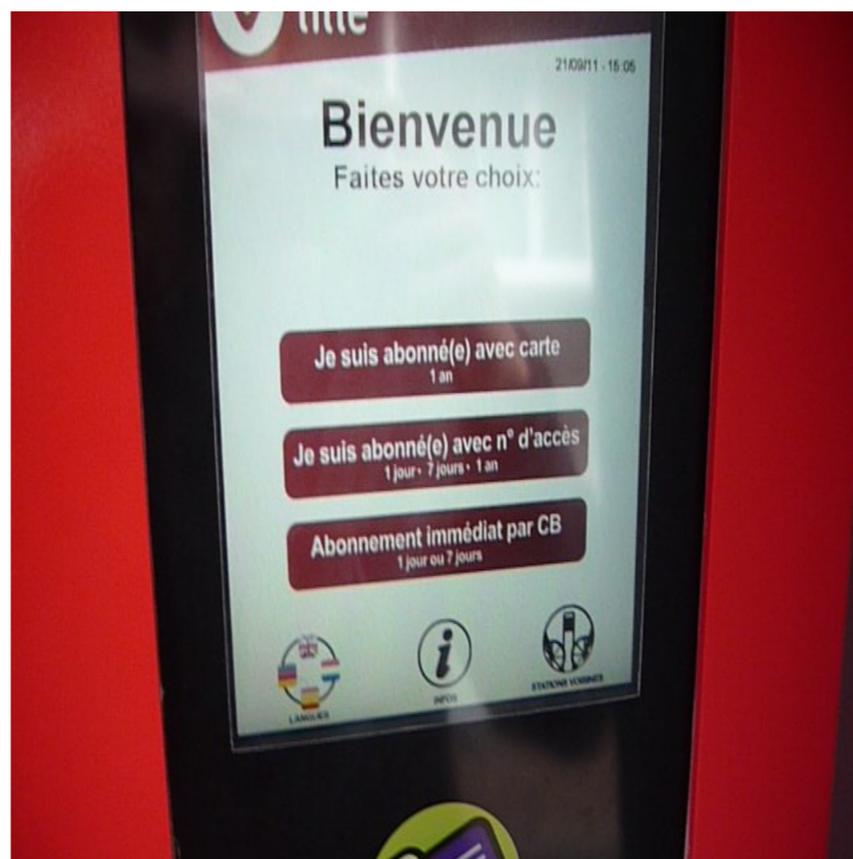


Technologie



Technologie tactile

- Nombre de périphériques tactiles dans les espaces publics



2007

2008

2009

2010

2011

2012₂₃

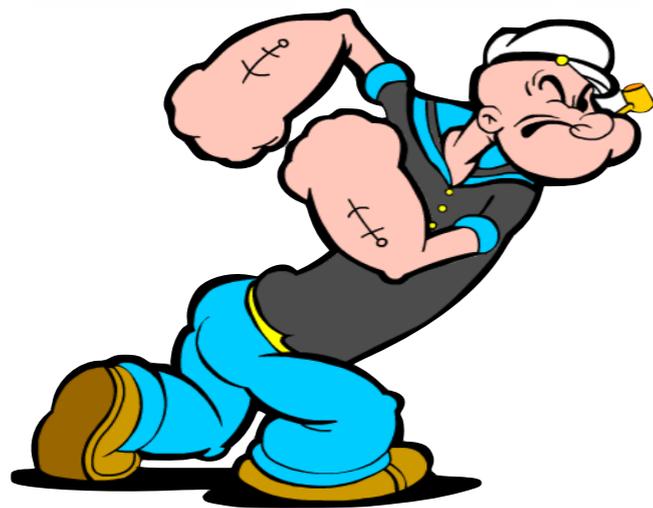
« Everything is best for something and worst for something else. The trick is knowing what is what, for what, when, for whom, where, and most importantly, why. »

–Bill Buxton

Avantages



Barrière d'entrée



Robuste



Plaisir



Sans fil

Multipoint vs souris



Multipoint vs souris



Multipoint vs souris

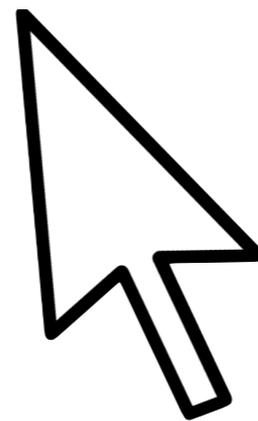
(2) Degrés de Liberté (DDL) intégrés



Multipoint vs souris

(2) Degrés de Liberté (DDL) intégrés

(1) pointeur

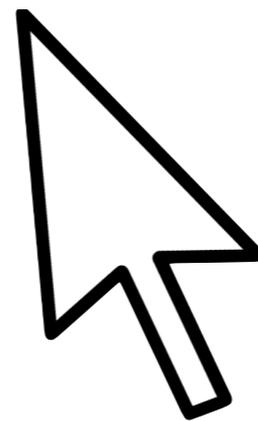


Multipoint vs souris

(2) Degrés de Liberté (DDL) intégrés

(1) pointeur

interaction *indirecte*



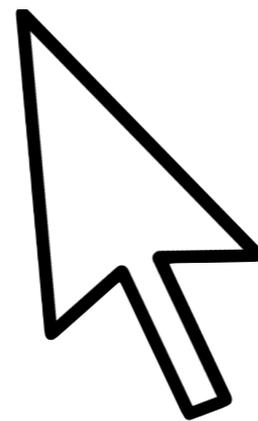
Multipoint vs souris

(2) Degrés de Liberté (DDL) intégrés

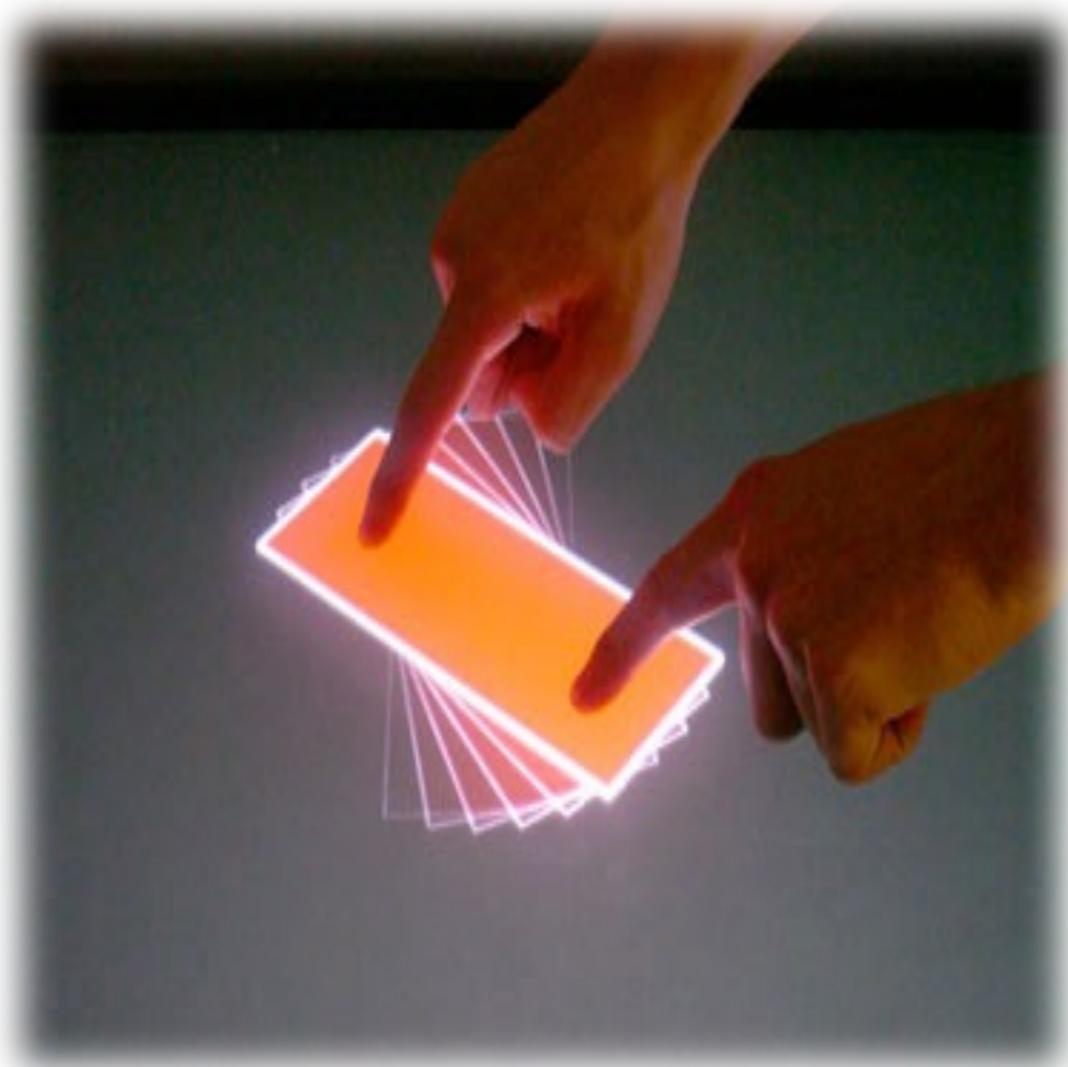
(1) pointeur

interaction *indirecte*

+1 DDL séparé



Directivité



Direct



Indirect

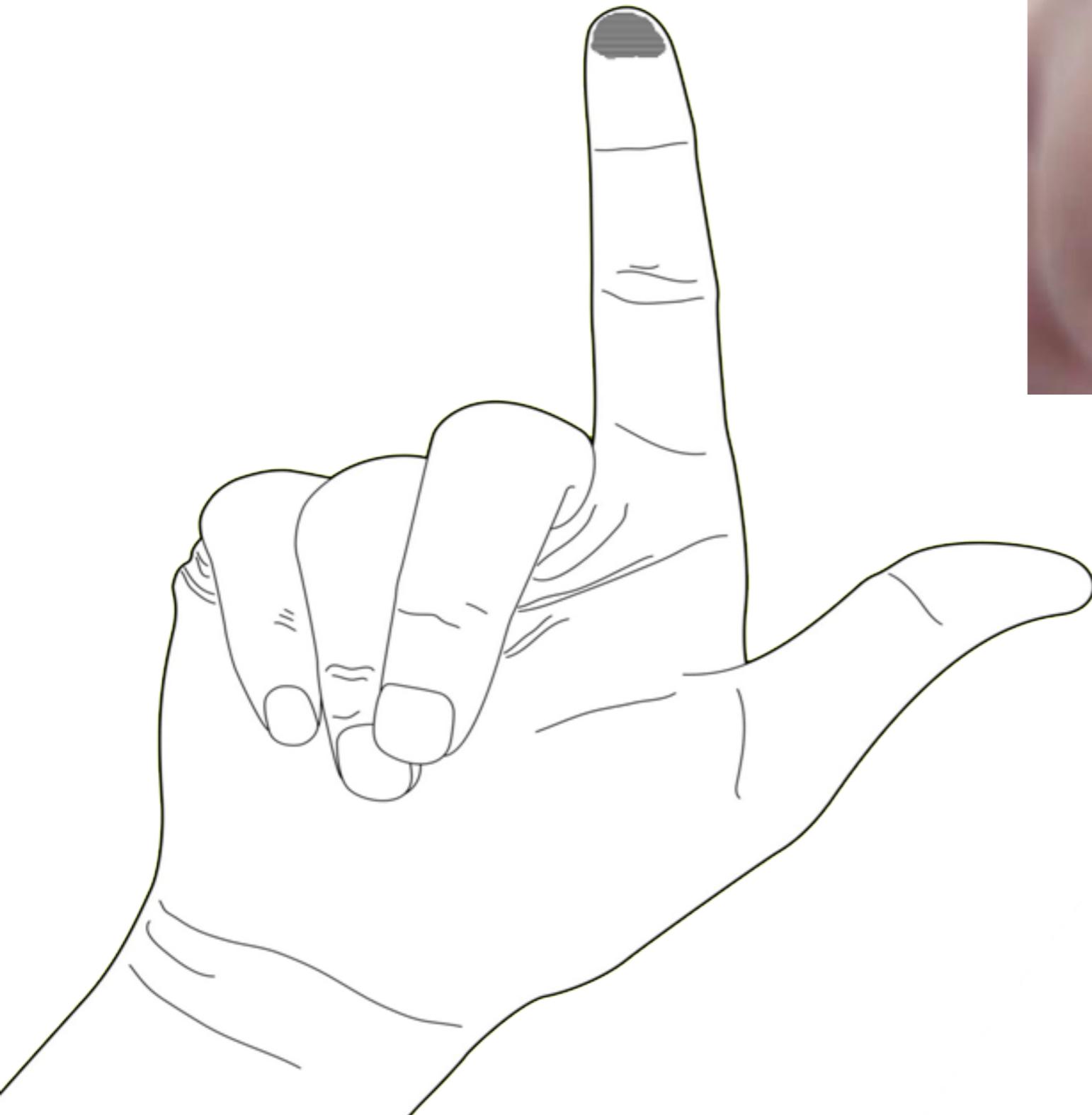
Problems

Fat Finger



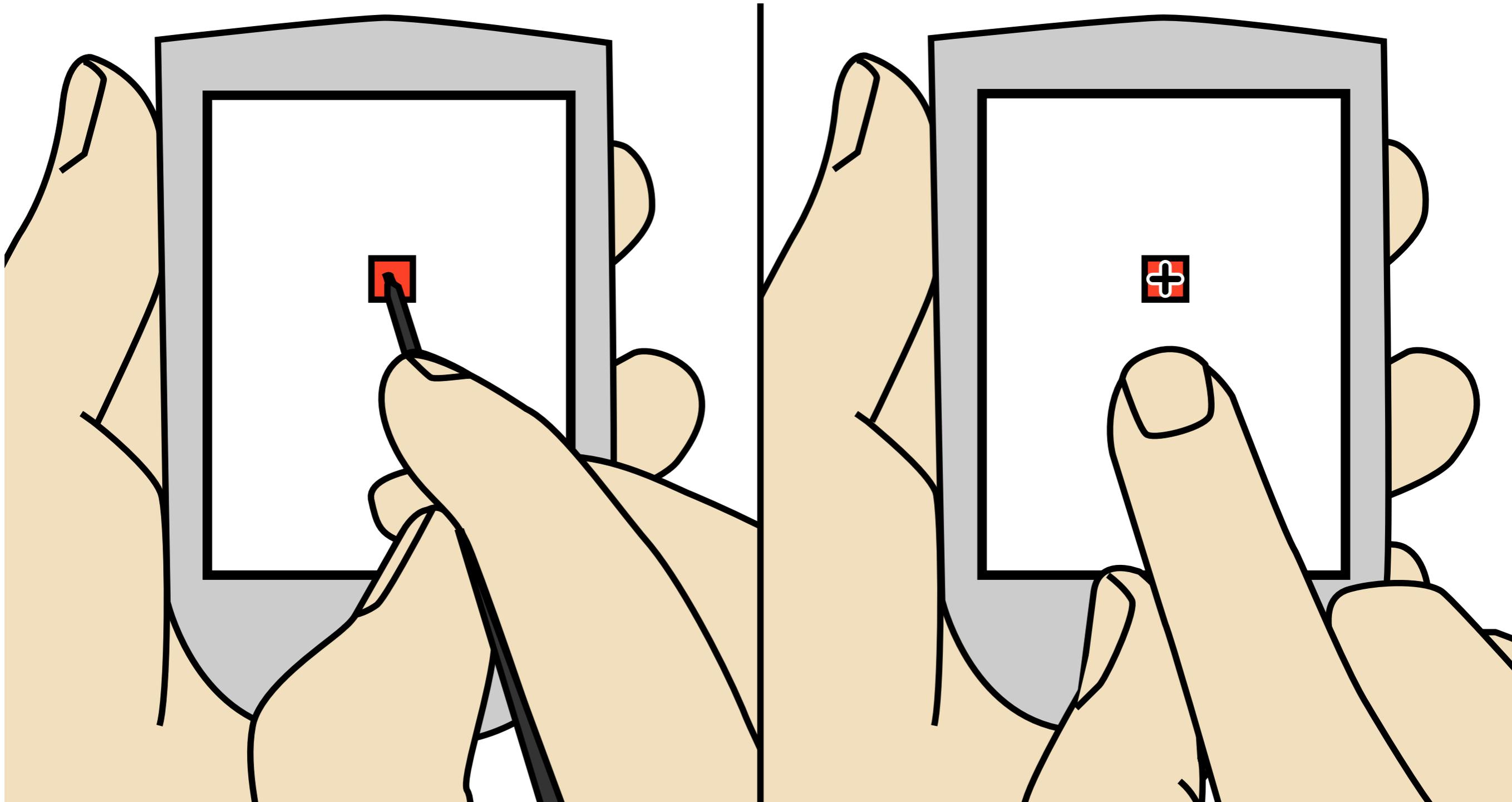
Problems

Fat Finger



Problems

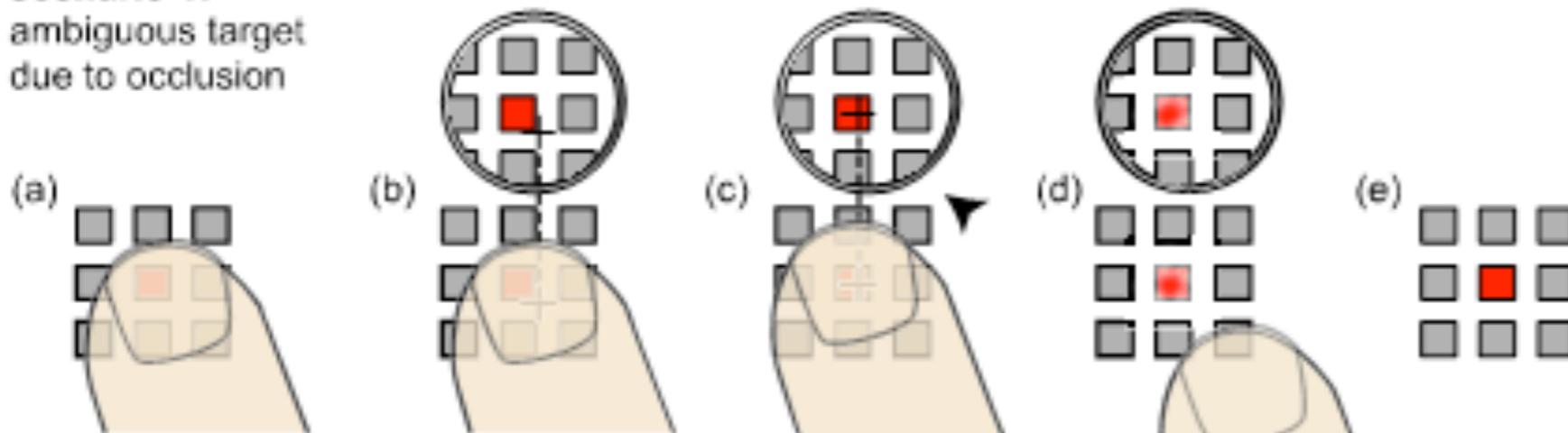
Precision



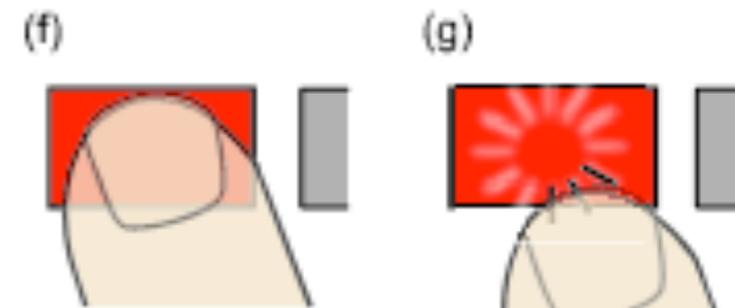
Shift

[Vogel et al. 2007]

scenario 1:
ambiguous target
due to occlusion



scenario 2:
occlusion not a
problem



Shift

[Vogel et al. 2007]



Shift

[Vogel et al. 2007]



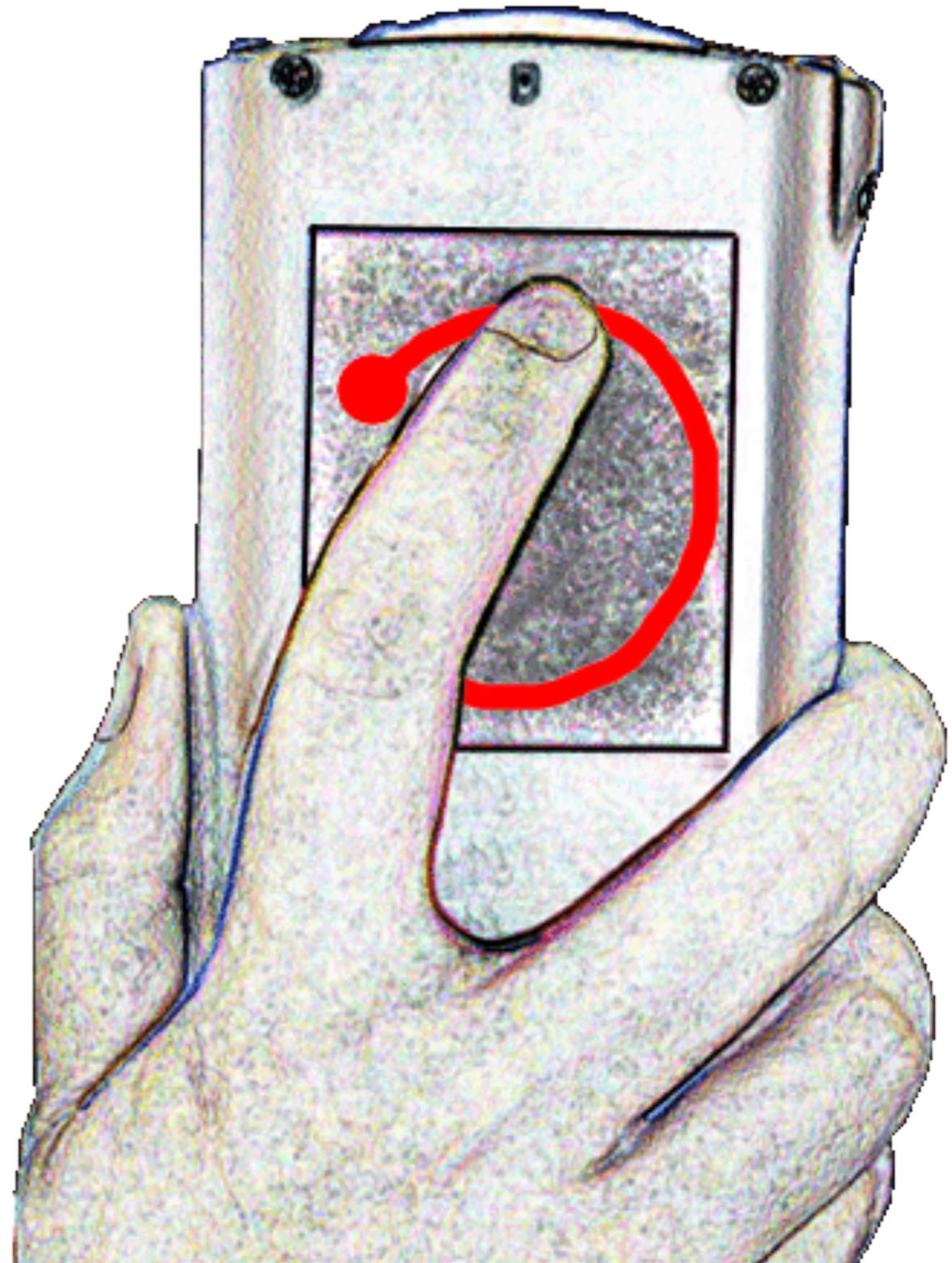
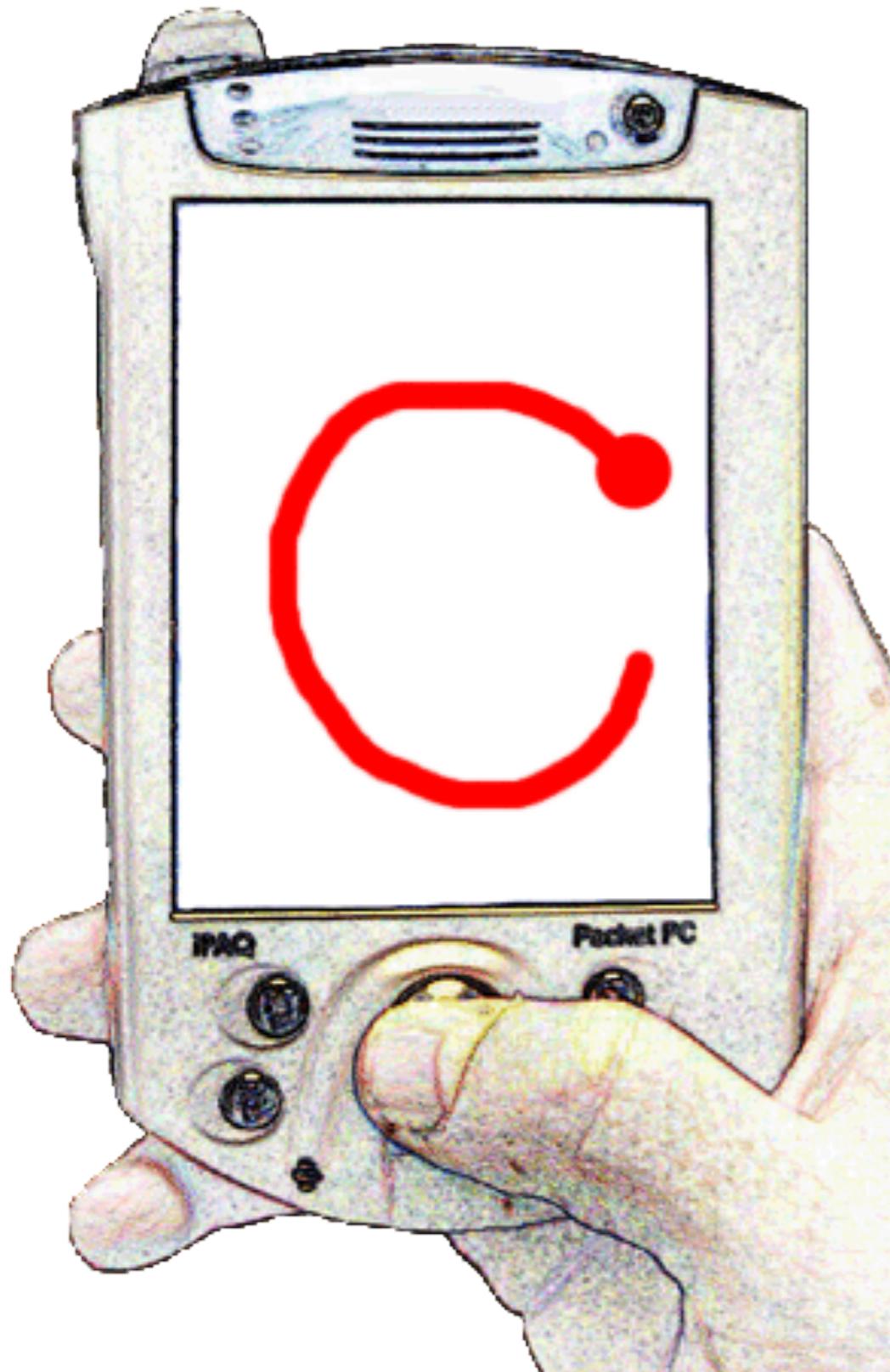
Behind touch

[Hiraoka et al. 2003]



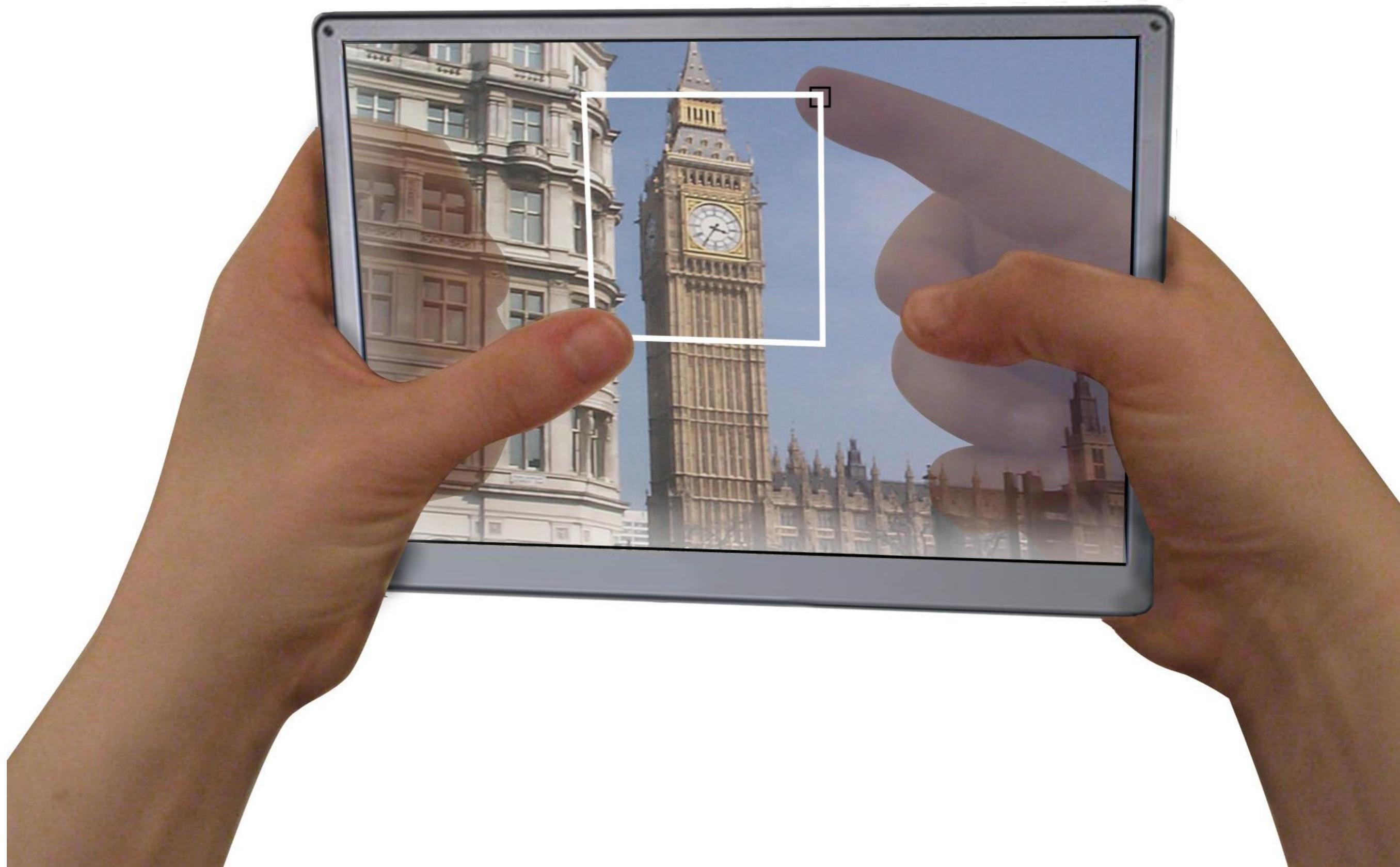
Behind touch

[Wigdor et al.]



Behind touch

[Wigdor et al.]



Lucid touch

[Wobbrock et al.]



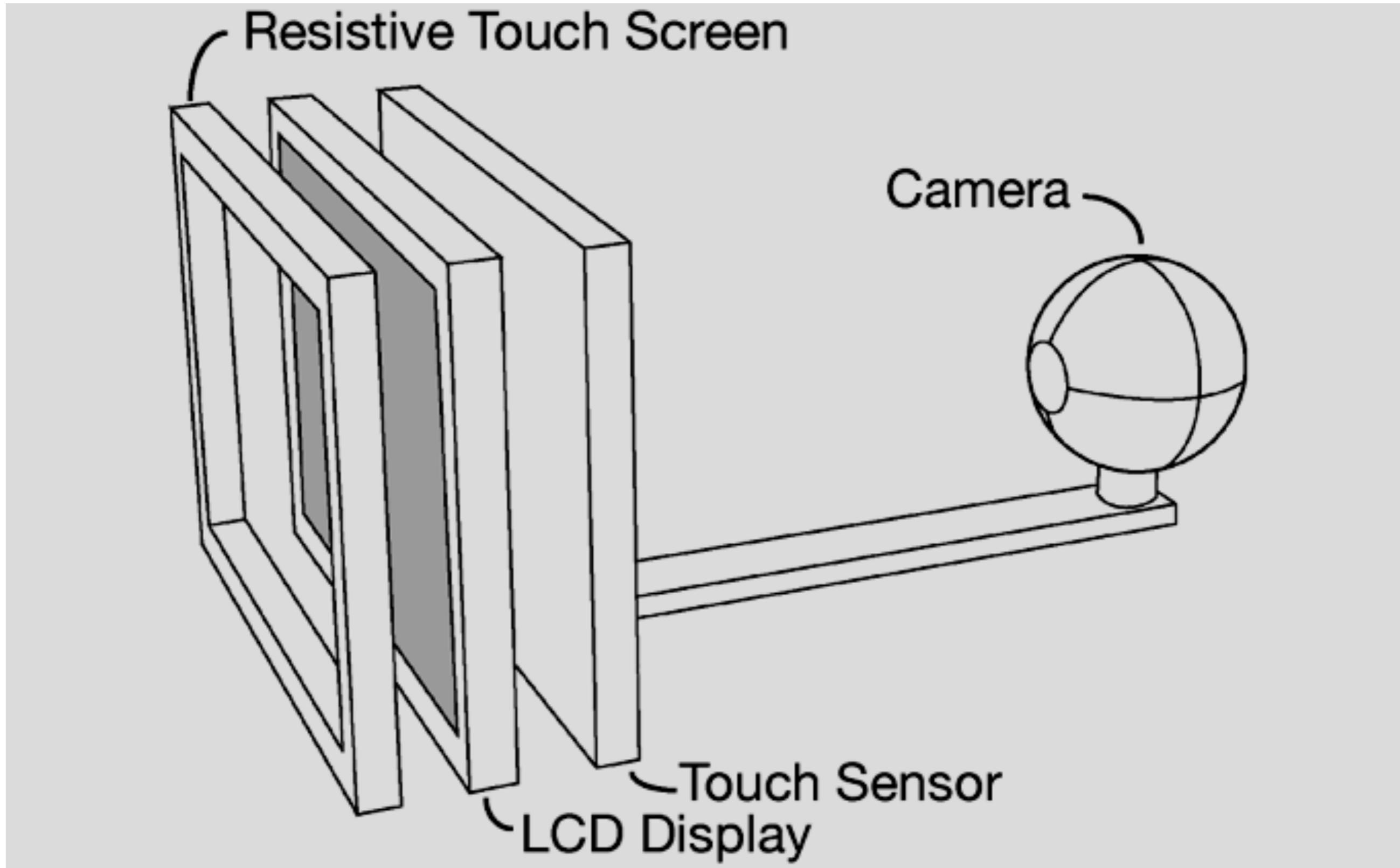
Lucid touch

[Wobbrock et al.]



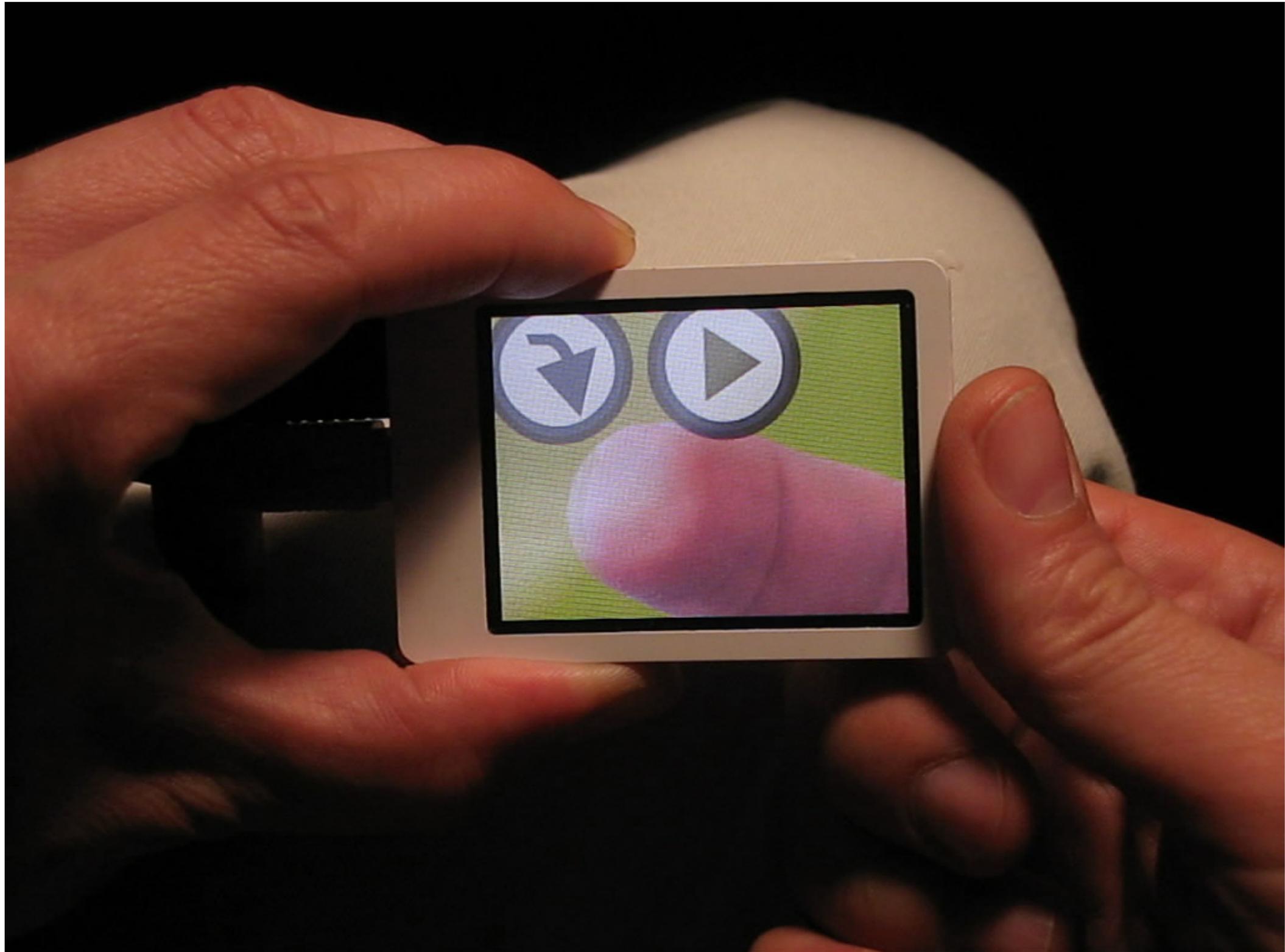
Lucid touch

[Wobbrock et al.]



Lucid touch 2

[Baudisch and Chu]



Lucid touch 2

[Baudisch and Chu]



Problem

Occlusion

Occlusion-Aware Interfaces

Daniel Vogel^{1,2} and Ravin Balakrishnan¹

¹Dept. of Computer Science
University of Toronto, CANADA

²Dept. of Math & Computer Science
Mount Allison University, CANADA

Problem

Occlusion

Occlusion-Aware Interfaces

Daniel Vogel^{1,2} and Ravin Balakrishnan¹

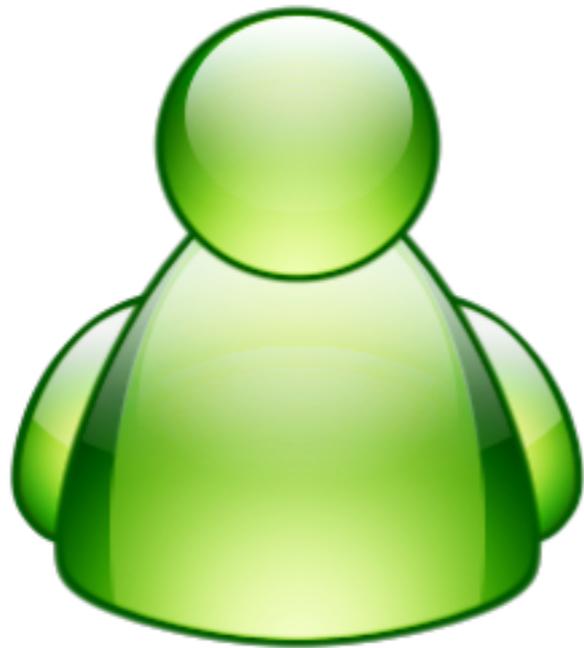
¹Dept. of Computer Science
University of Toronto, CANADA

²Dept. of Math & Computer Science
Mount Allison University, CANADA

Contexts / usages



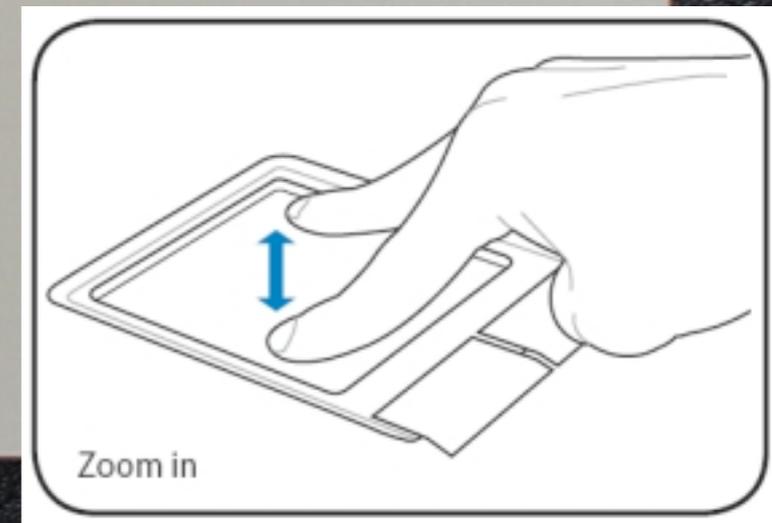
1 user



Smartphone, Tablets



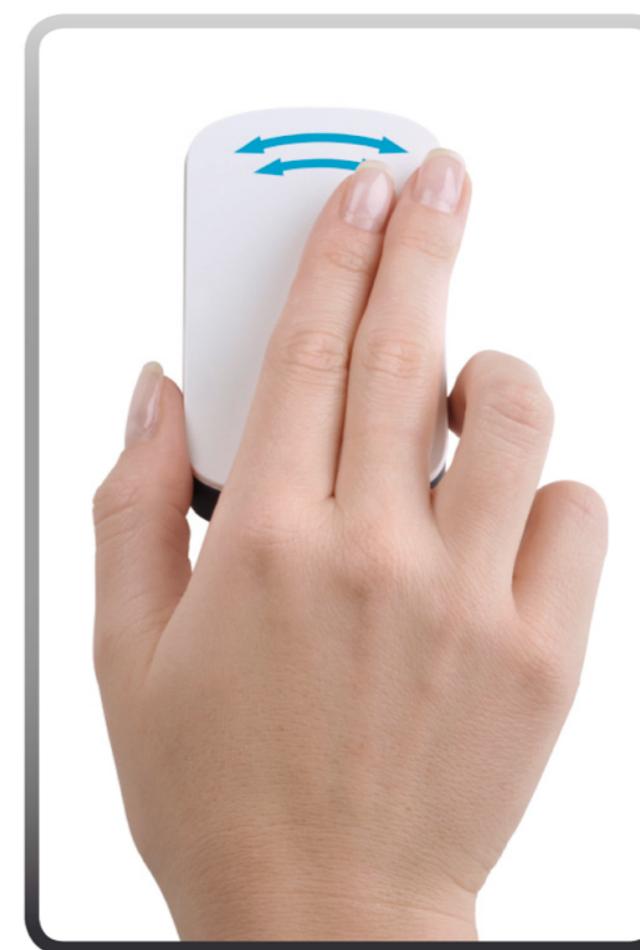
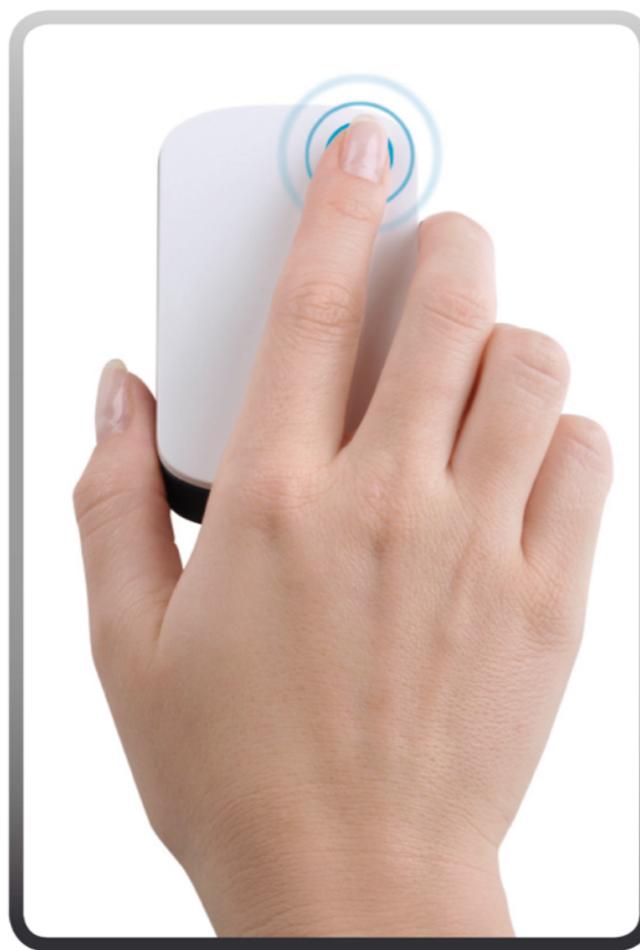
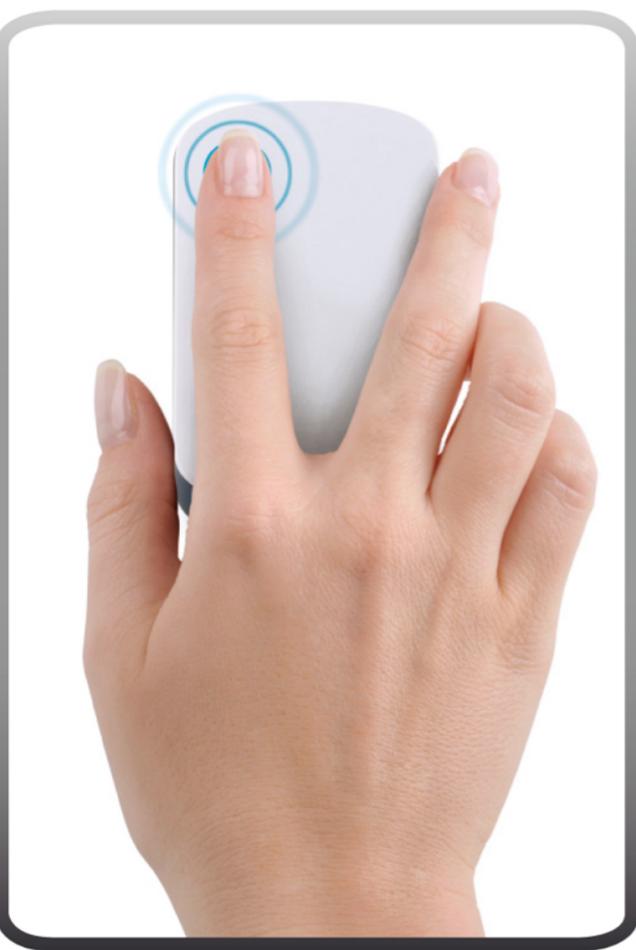
TouchPad:
multitouch + pressure + Tactile feedback



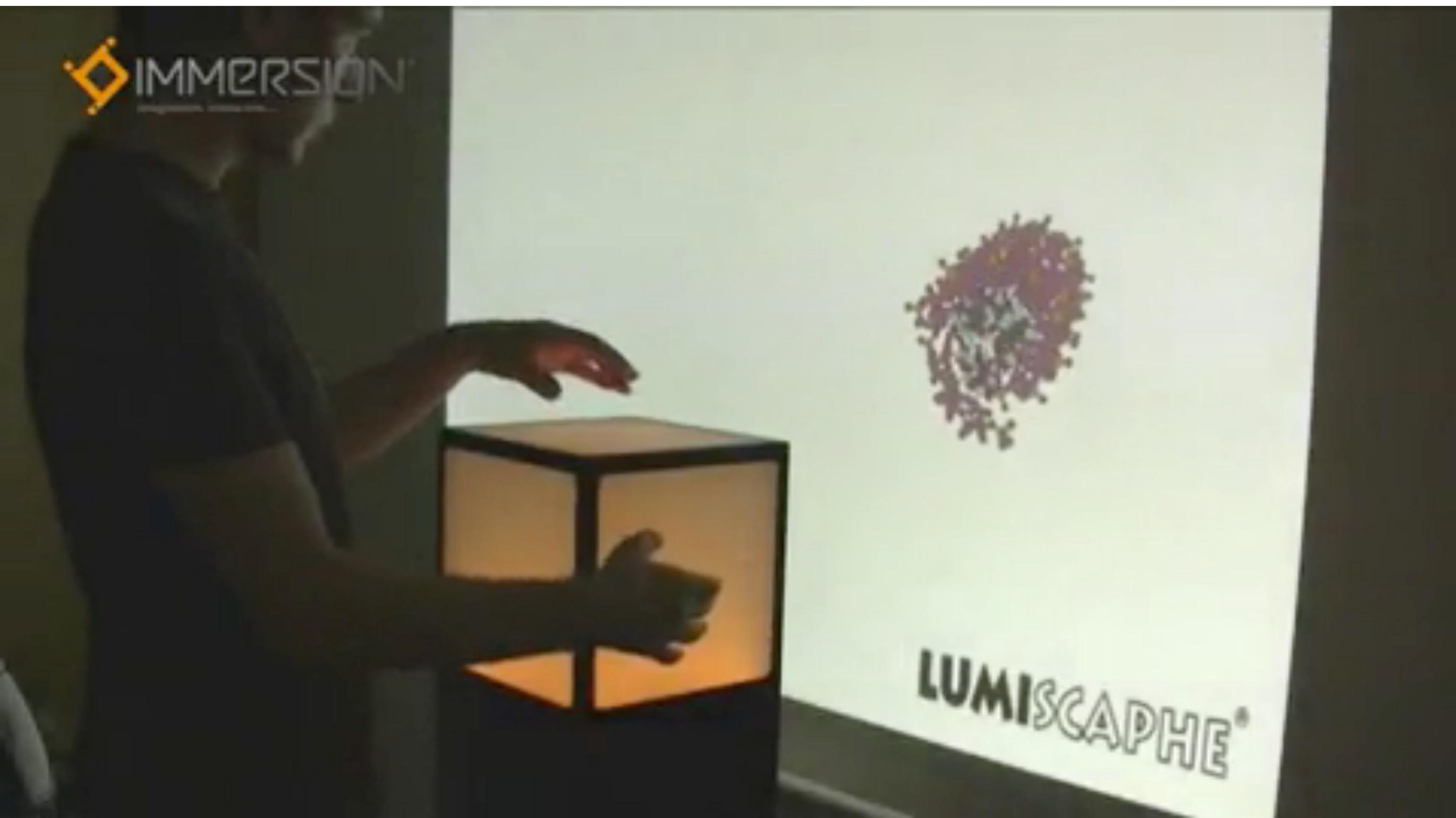
Touchscreen



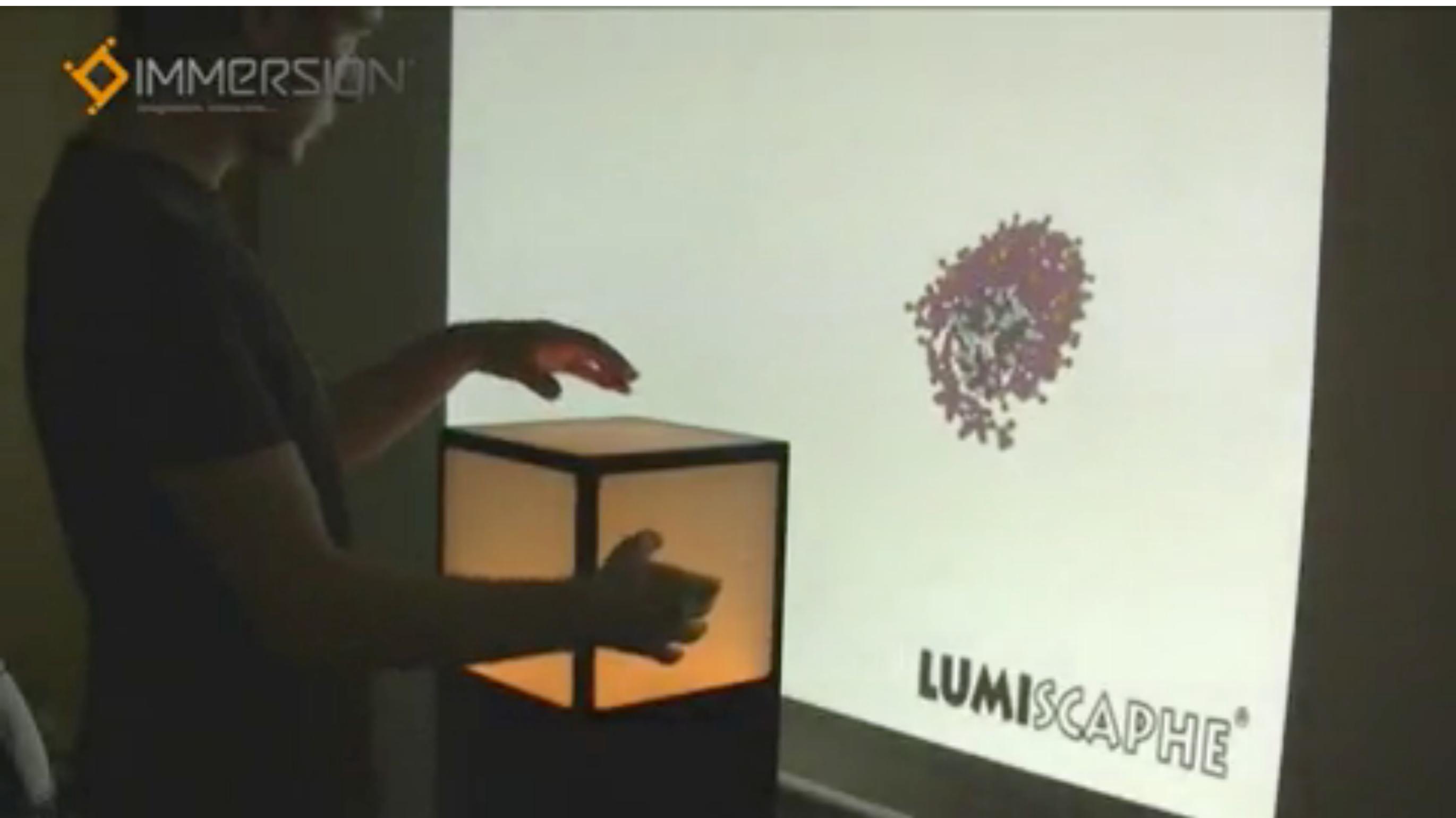
Mouse



CubeTile [Immersion]



CubeTile [Immersion]



Sphere



Microsoft Sphere

Surfaceless



CAMERA

COLOR MARKERS

PROJECTOR

MIRROR

GENERAL CENTER
Times: Morning edition published at 6 a.m., 8:30 a.m., 11 a.m., 1:30 p.m., 4:30 p.m.
Phone: 617-552-1111
Fax: 617-552-1111

In the news

President-elect Barack Obama will call for about \$300 billion in tax cuts as his administration plans, countering Republican worries that he would only too readily increase spending. **A2**

A suicide attack on Shi'ite Muslim pilgrims killed up to 30 people and wounded 72 in one of the worst assaults in Baghdad in months. **A3**

Drama should be abundant this year in the Boston City Council, which must deal with a political campaign, a fiscal crunch, and a member under criminal indictment. **B1**

A Beth Israel Deaconess urologist helps challenge a longstanding prohibition against giving testosterone to men who have had prostate cancer. **A5**

Early in the season, the Massachusetts golf club's early season starts. **B1**

Virginia Governor Dean K. Young's Democratic Party. **A2**

Company's technology... **B1**

Parents could have greater... **A2**

Medicines... **B1**

... **B1**

... **B1**

... **B1**



FOR THE PROJECT PURPOSE ONLY
Smoke rose as Israeli infantry soldiers walked into Gaza yesterday. The battles so far have been outside urban areas.

Israelis split Gaza in two amid calls for a cease-fire

By Ethan Bronner
NEW YORK TIMES

ON THE ISRAELI-GAZA BORDER — Israeli soldiers split Gaza into two parts yesterday, the Israeli military said. The soldiers moved into the northern part of the strip, which is controlled by Hamas, and the southern part, which is controlled by Fatah, the main rival of Hamas.

ground combat appeared to have been comparatively restrained. Hamas, the Islamist rulers of Gaza, had warned that Israeli soldiers would be killed if they entered the strip.

Israeli soldiers said they had found a large cache of weapons in the northern part of the strip, including rockets and mortars.



As rich rivals cut back, small colleges sell stability

Rely on tuition, not endowment

T

Obama Cabinet nominee pulls out

Contract in... bogs down R...

First bump in process for president-elect

Richardson... Bill Richardson... drawing as... commerce and... investigation into how... of Richardson's political... donors won \$1.5 million in state contracts. The move represented the first public snag in Obama's attempt to assemble his Cabinet.

Richardson denied wrongdoing but said the investigation would probably remain unresolved until well after Obama's inauguration and he didn't want to disrupt the new administration.

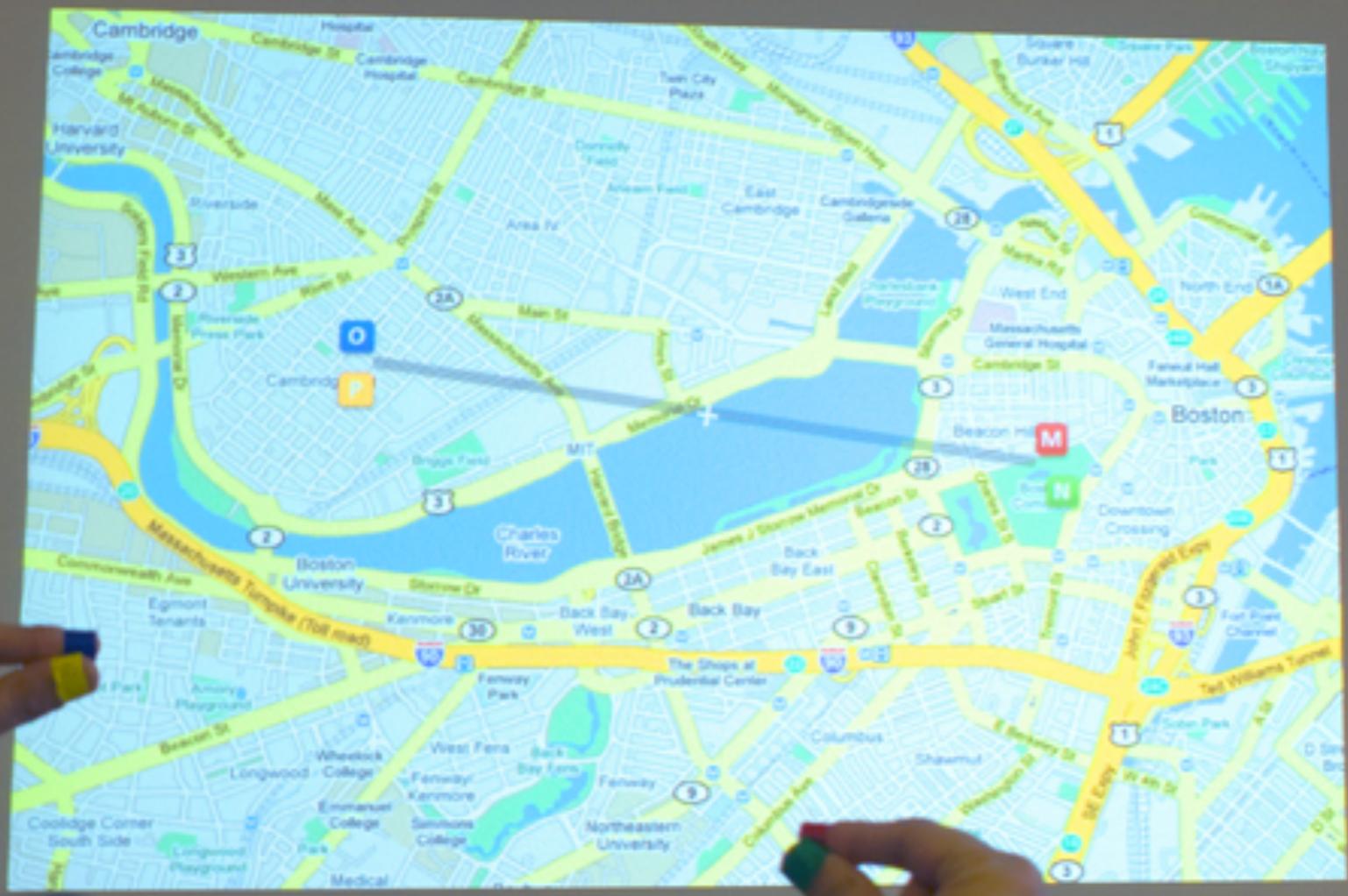
"Let me say unequivocally that I and my administration have acted properly in all matters and that this investigation will bear out that fact," Richardson, who also served in the Clinton Cabinet, said in a statement released by Obama's transition team. "But I have concluded that the ongoing investigation also would have served an important role in the construction process."

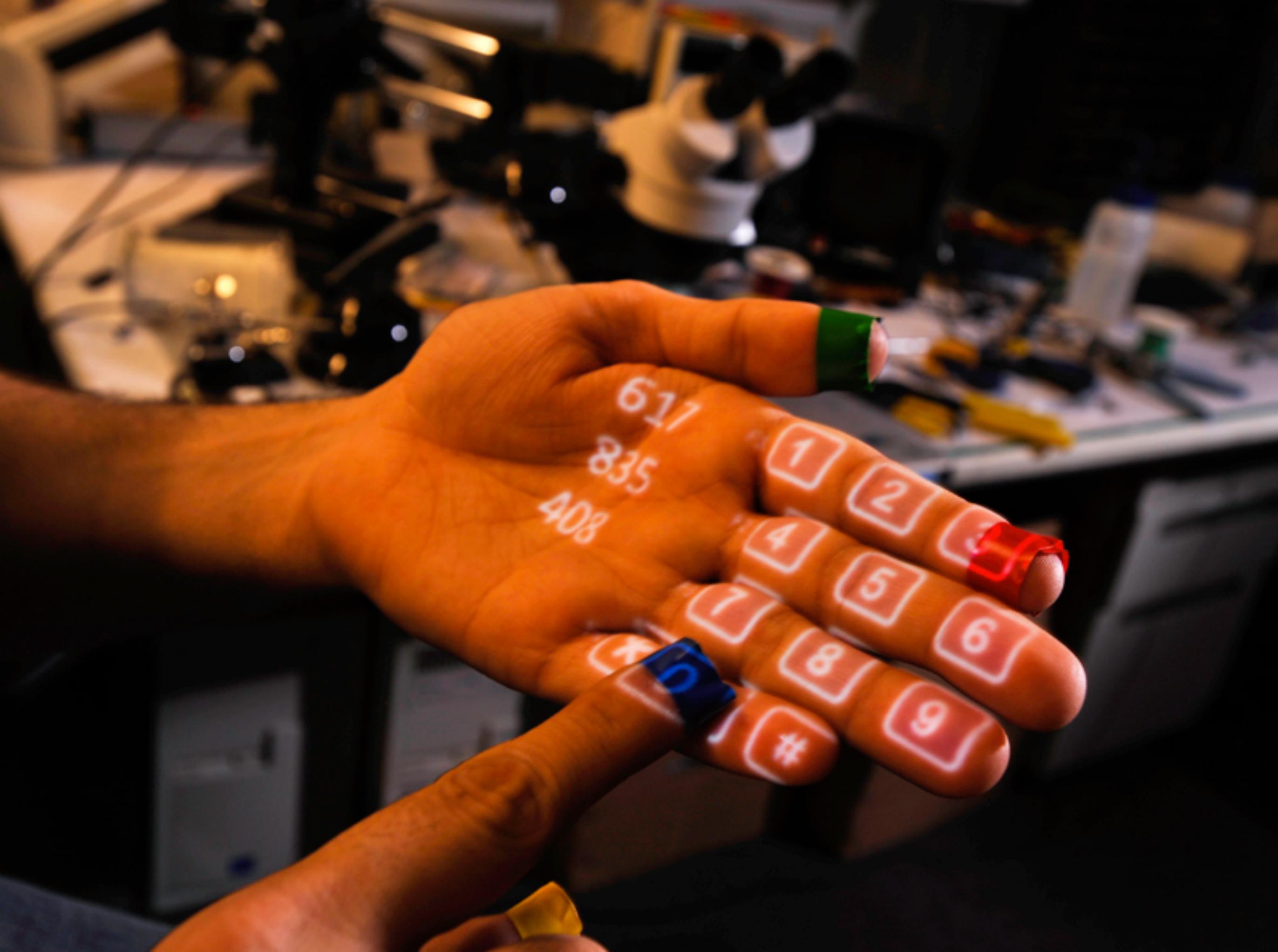
Obama had tapped Richardson for the... **PAGE A12**

Church struggles to keep its voice

Christ...



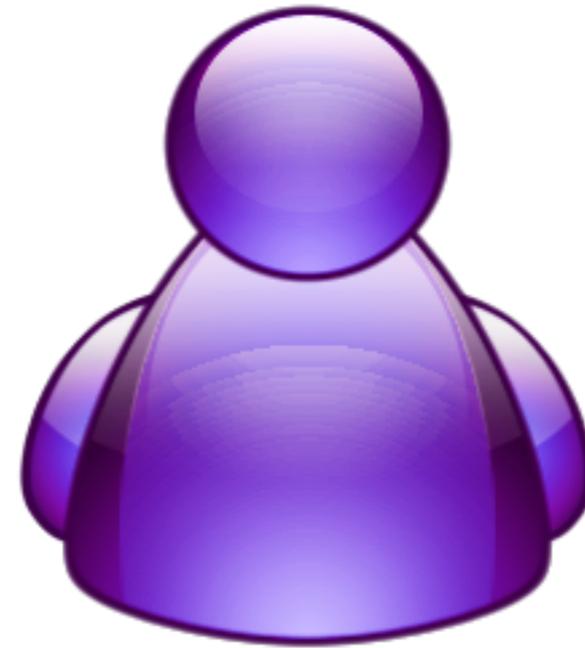
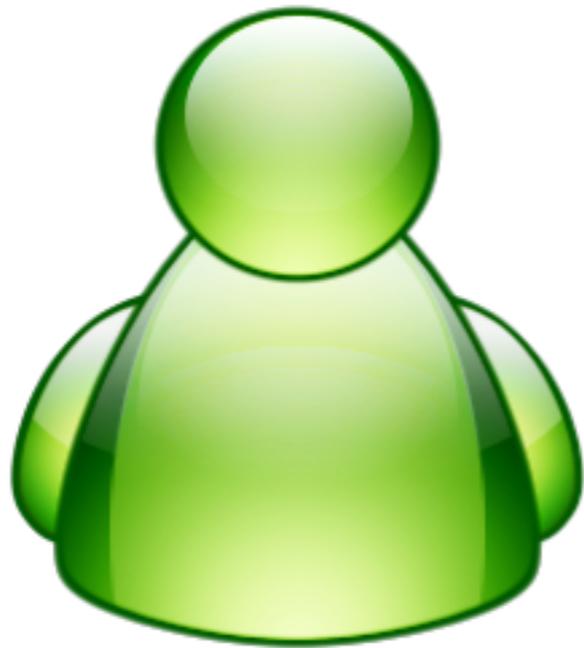




617
835
408

1 2 3
4 5 6
7 8 9
* 0 #

2 users





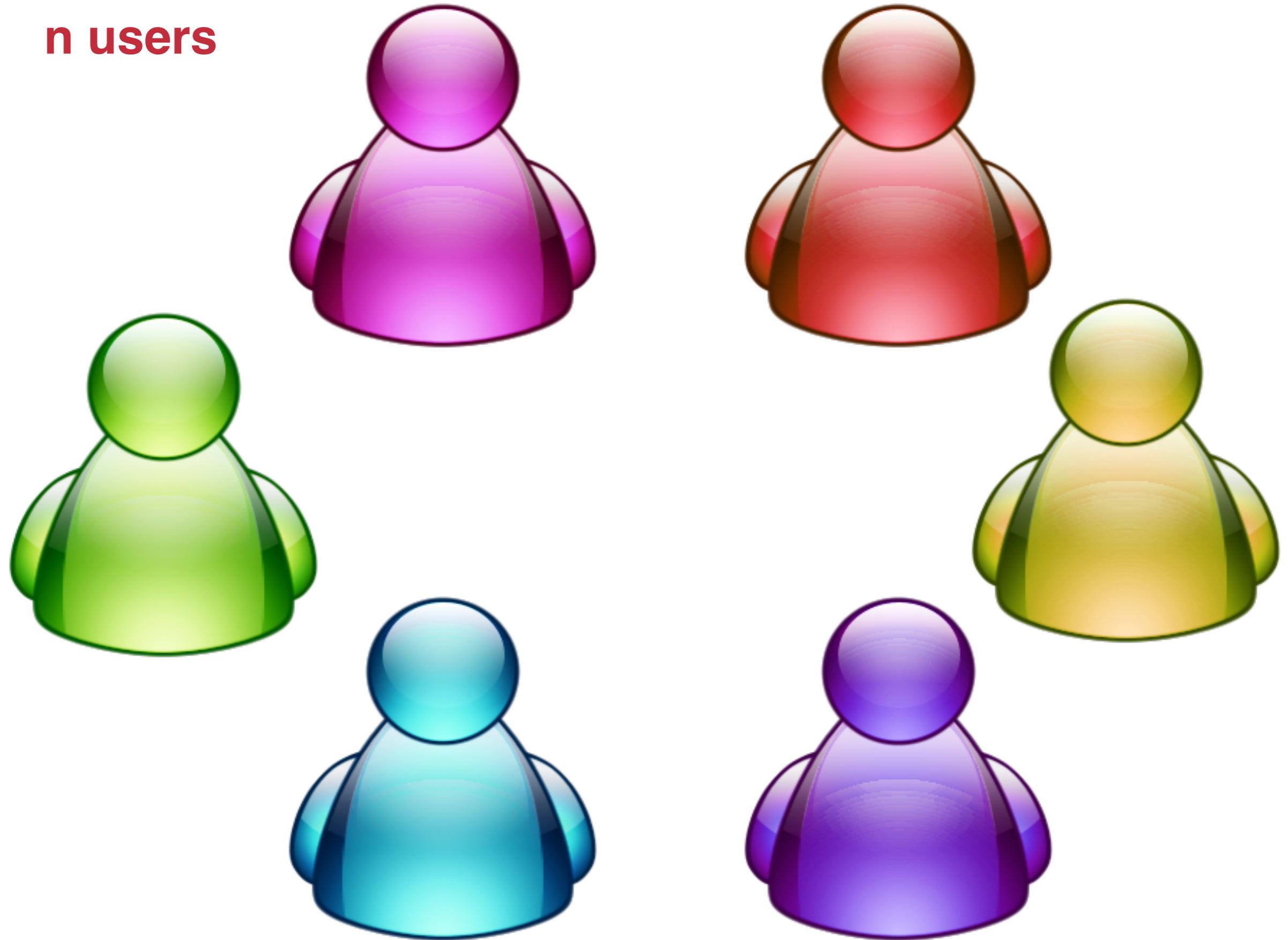


Coffee Table



Microsoft Surface

n users



Tabletop



TableTop

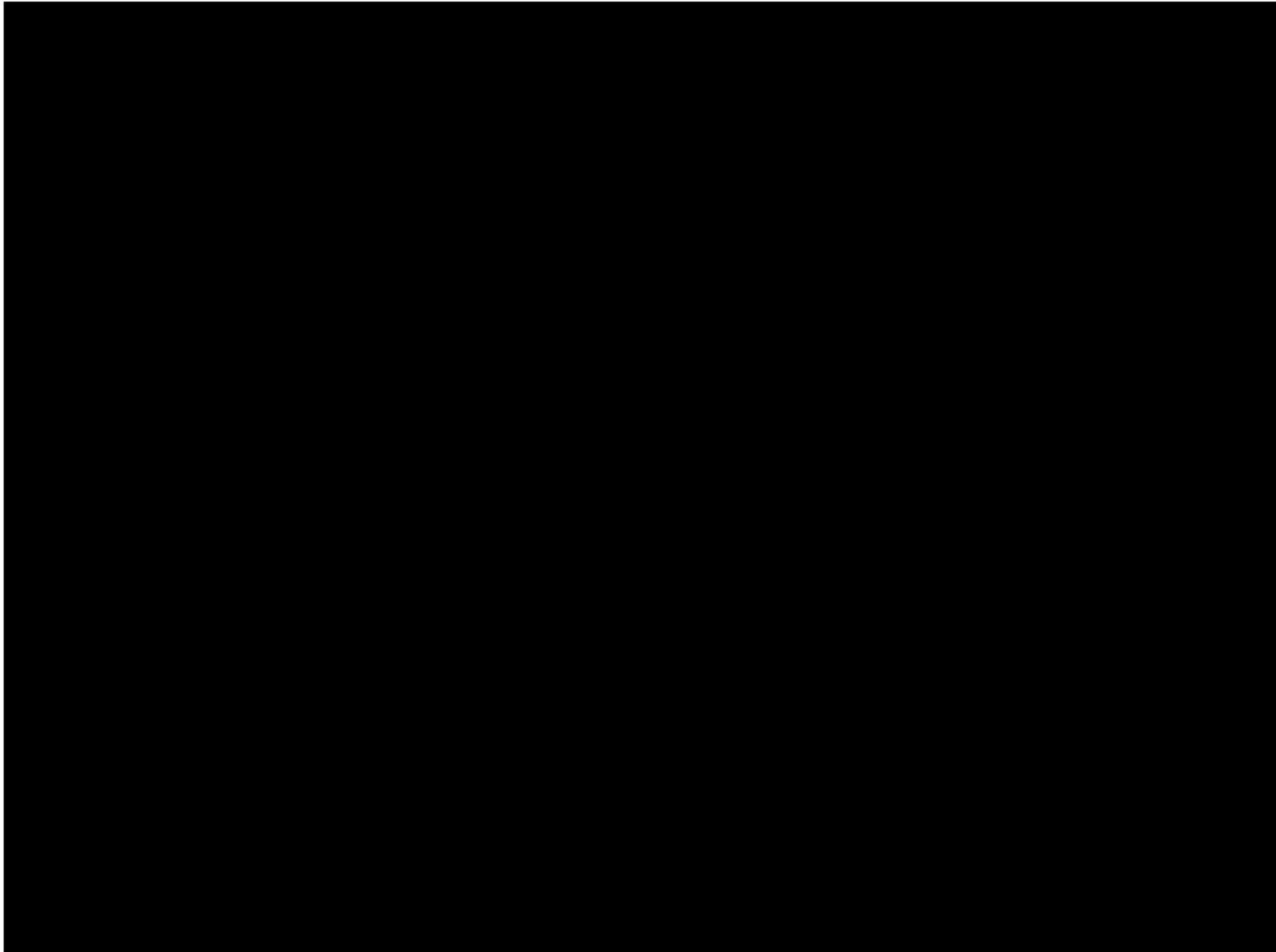
Reactable



<http://reactable.com/>

TableTop

Reactable



<http://reactable.com/>

Interactive wall displays



Interactive wall displays

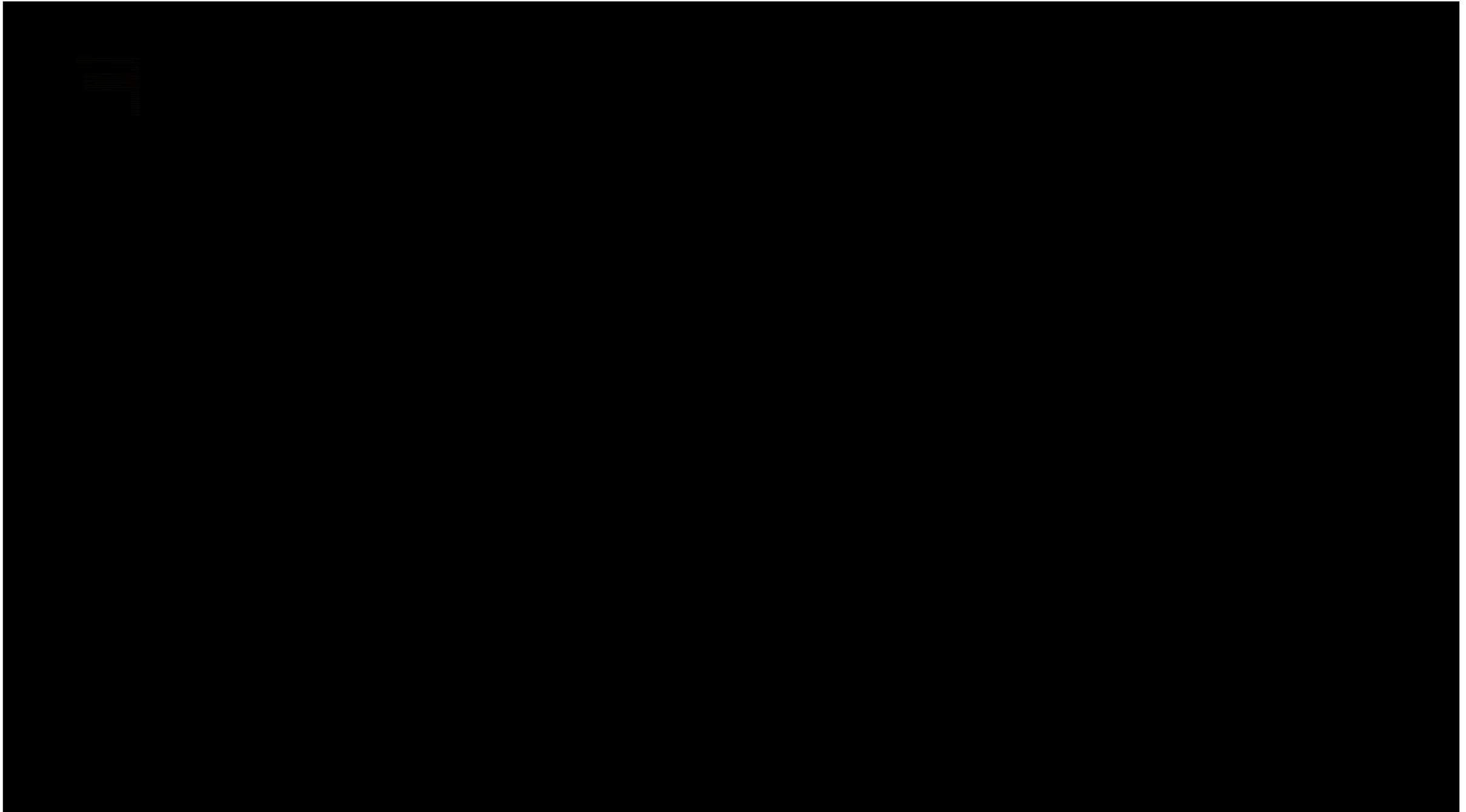


Interactive floor



Interactive Floor

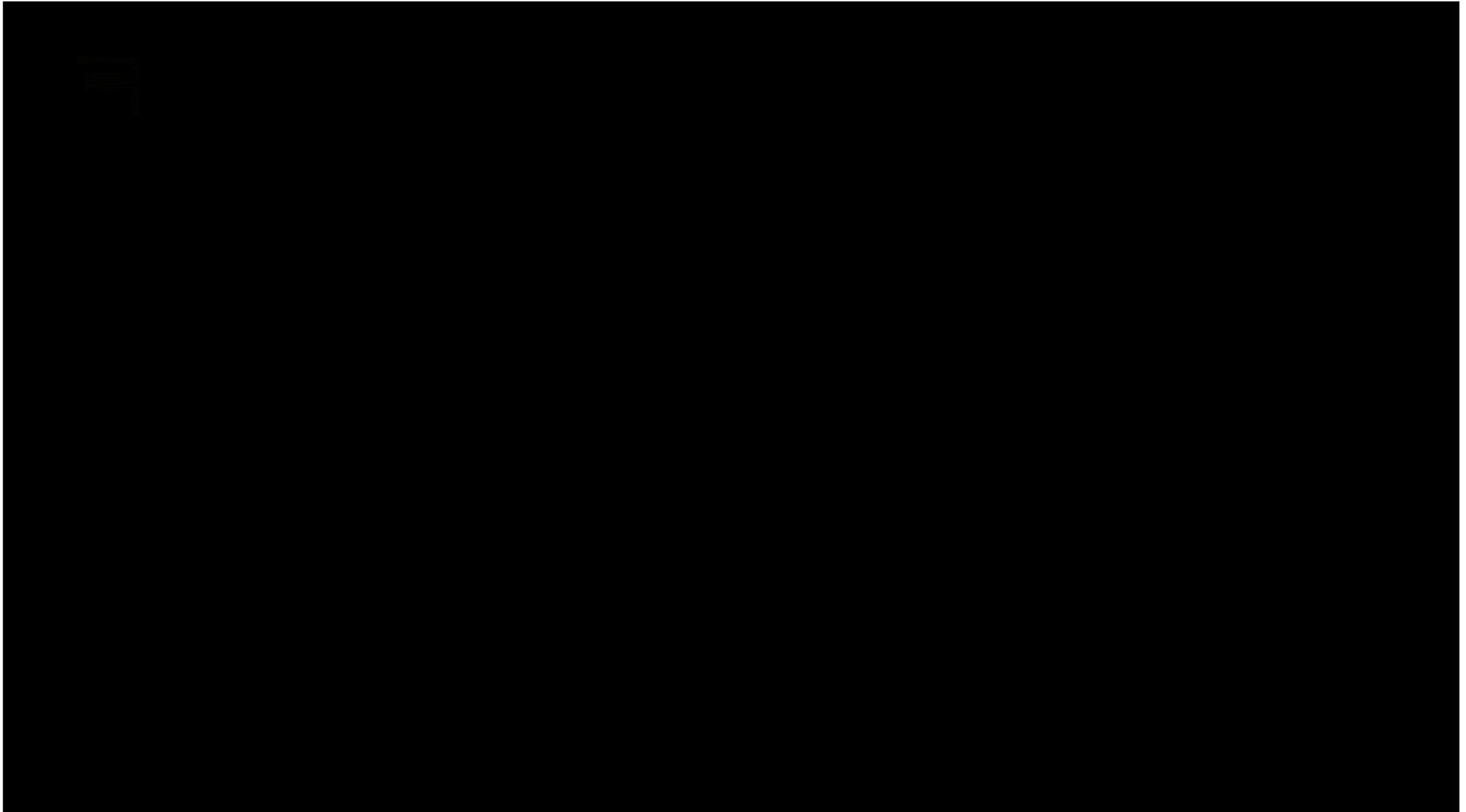
Multitoe [Fetzer et al.]



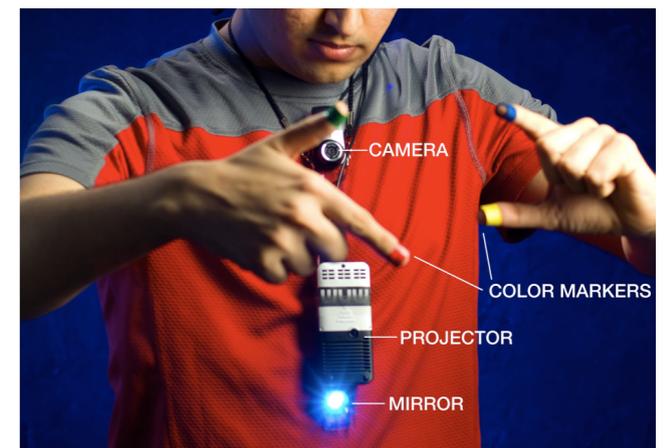
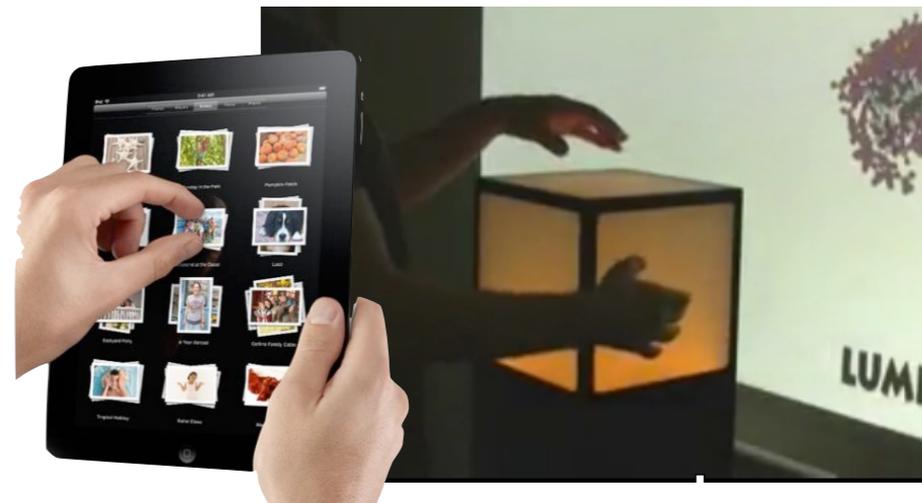
<https://hpi.de/baudisch/projects/multitoe.html>

Interactive Floor

Multitoe [Fetzer et al.]



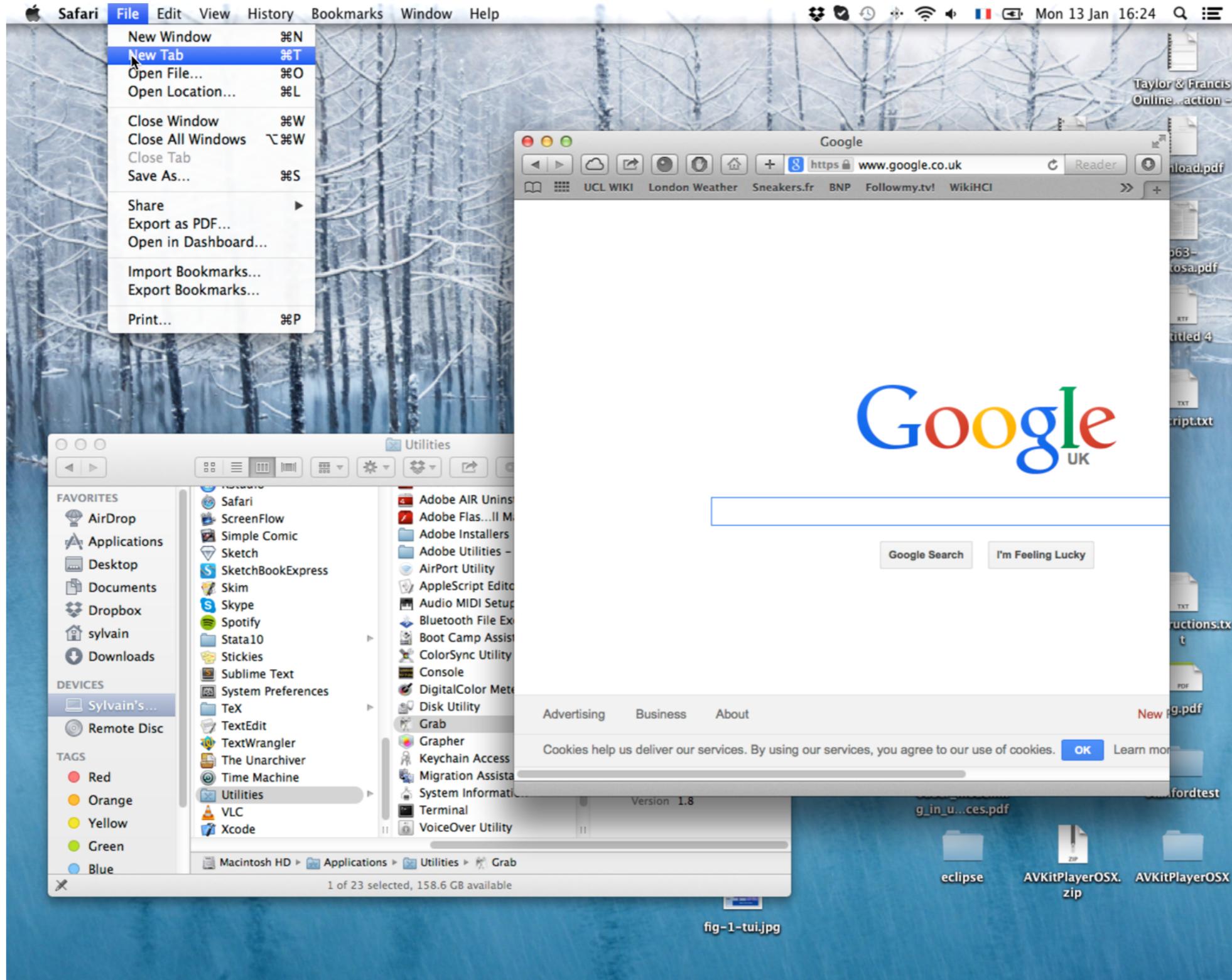
<https://hpi.de/baudisch/projects/multitoe.html>



Interaction gestuelle

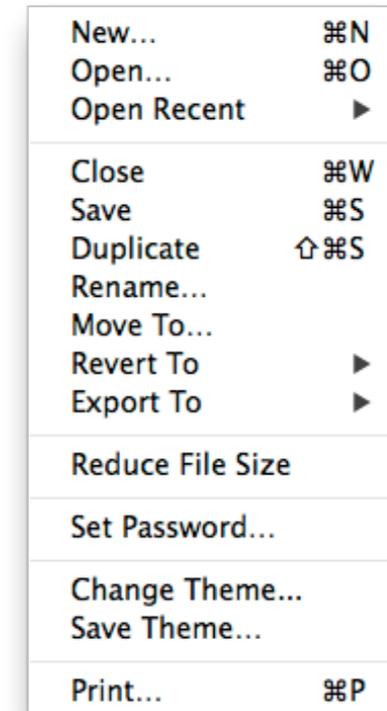
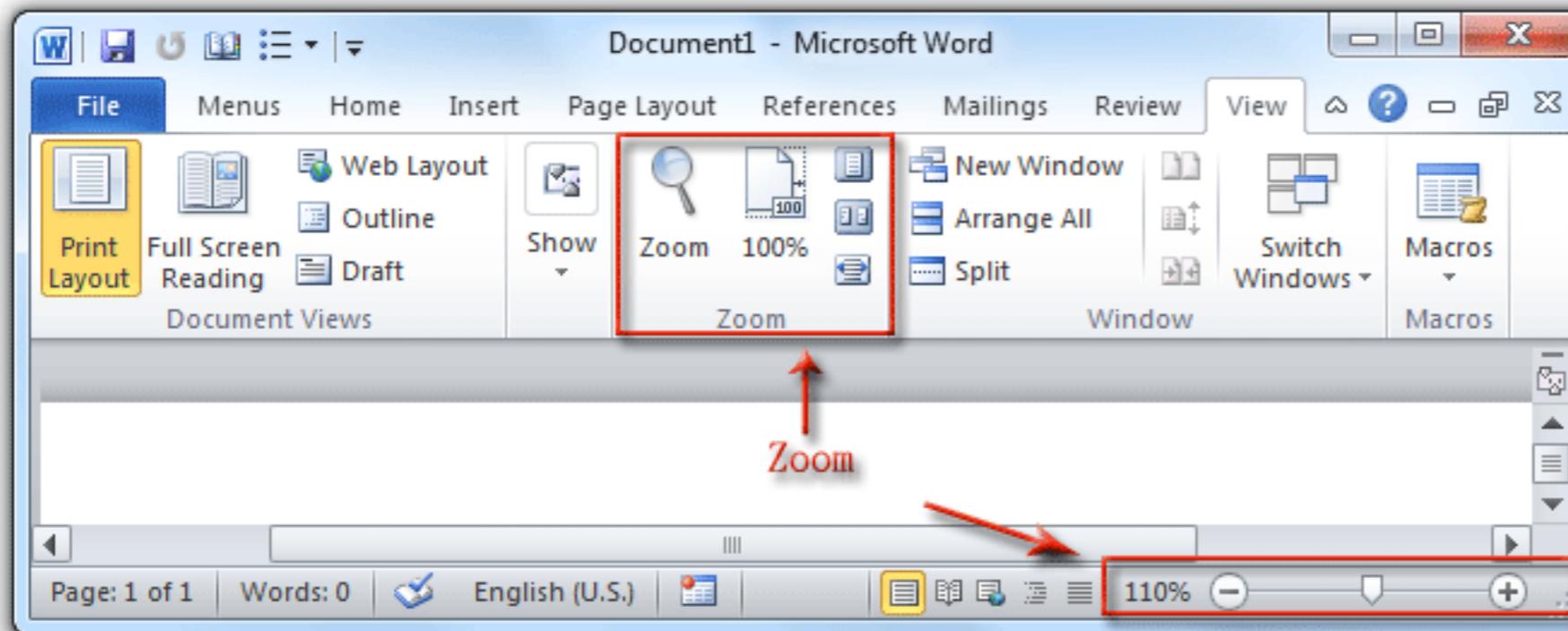


Windows Icons Menus Pointer



Pas “suffisamment directe”

Interaction *indirecte* via la manipulation d'elements graphiques





Inadaptée



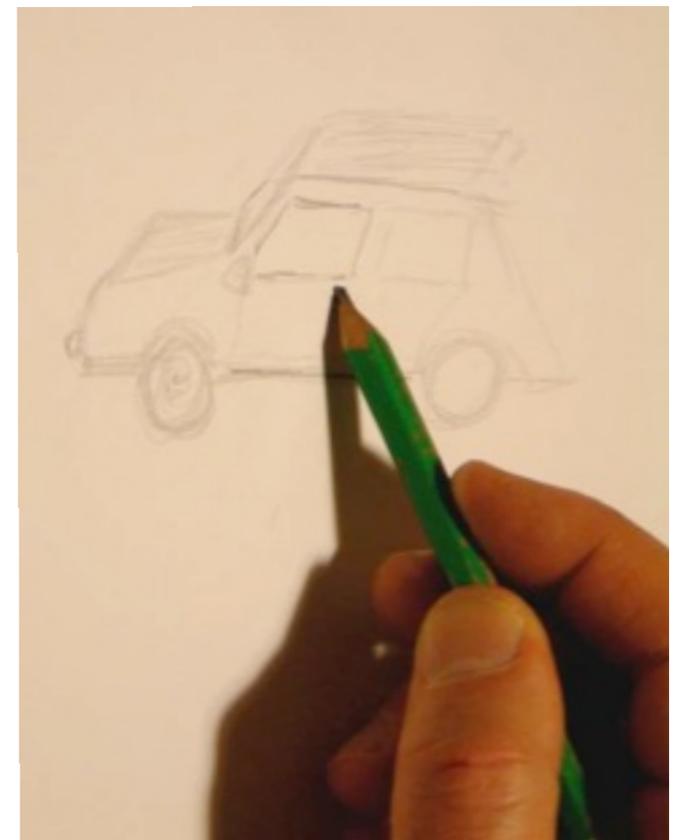
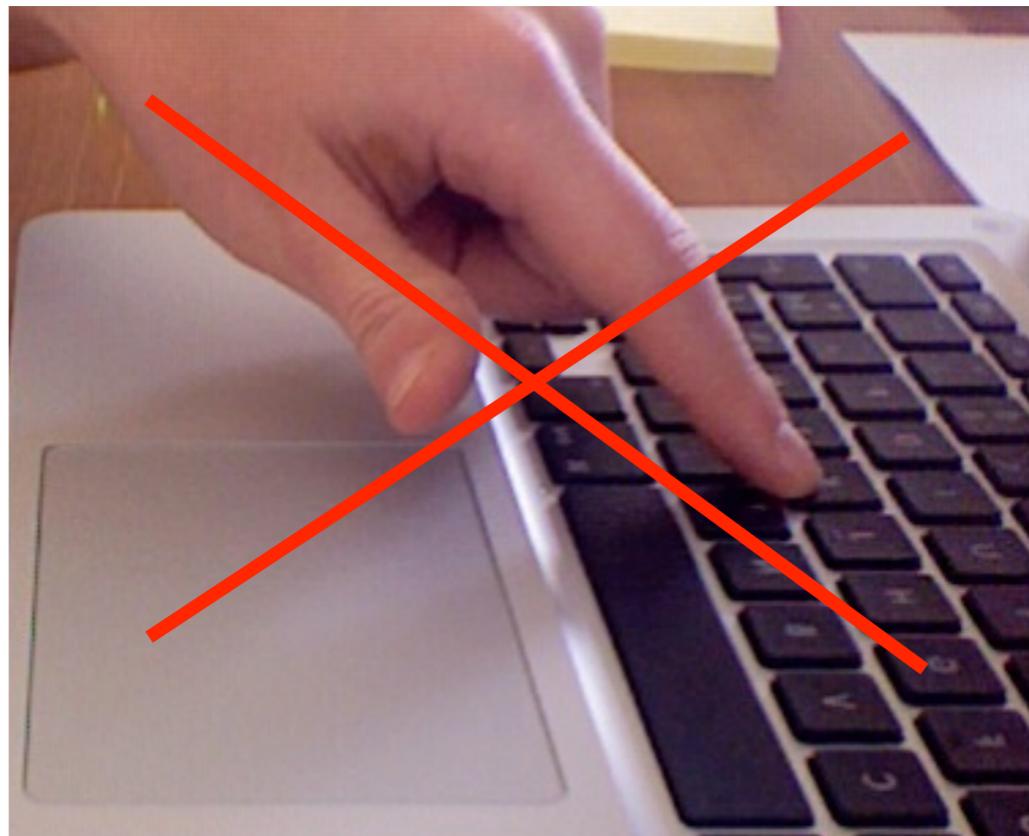
Inadaptée





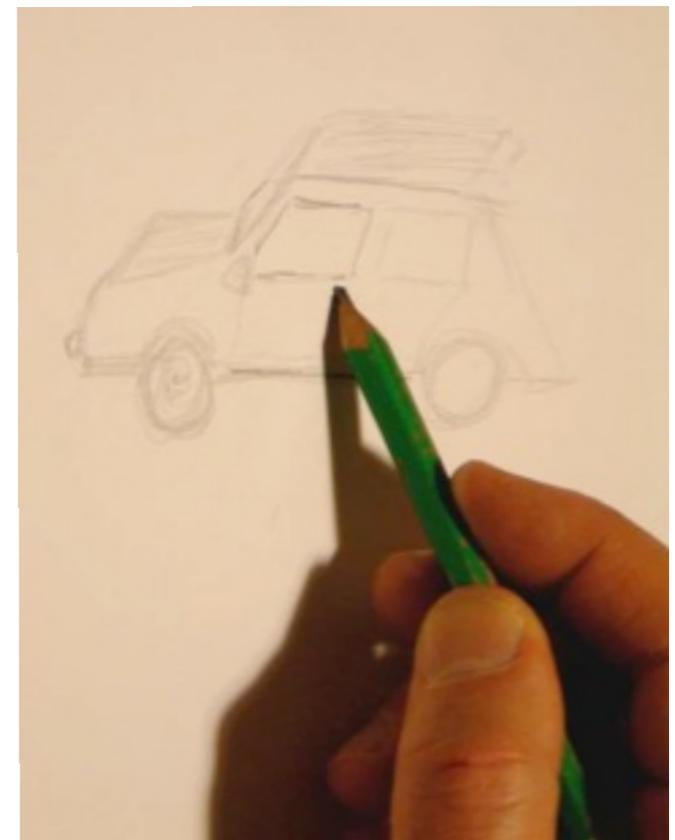
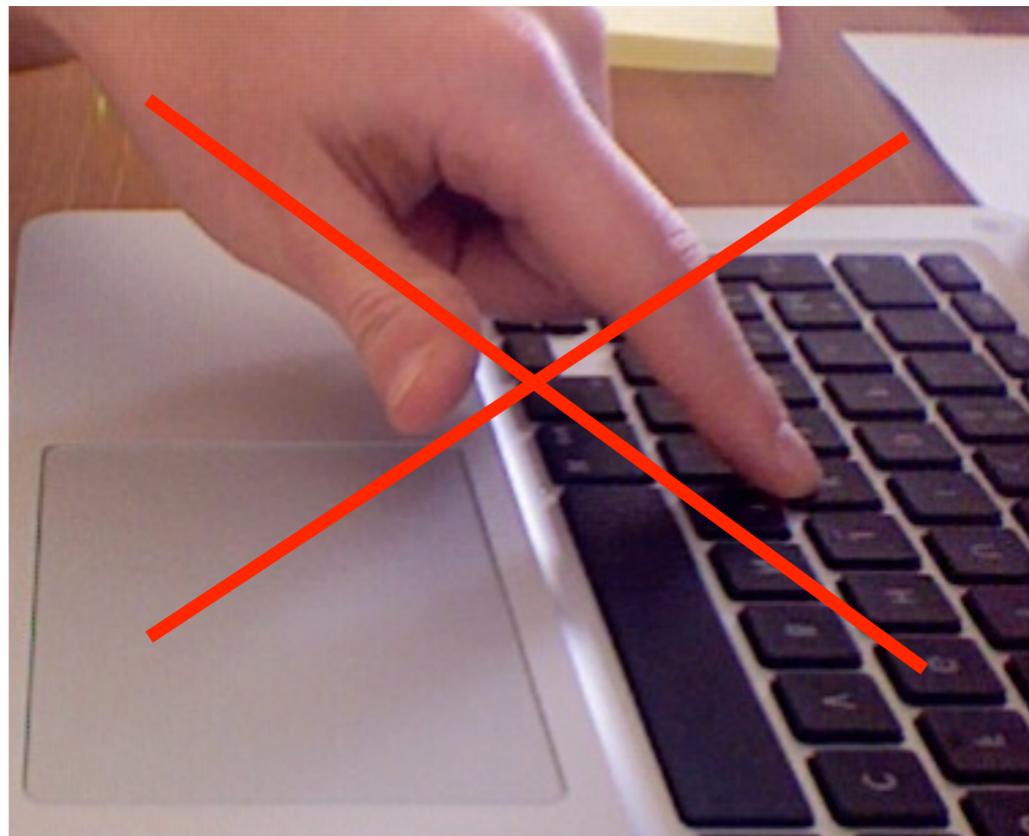
Definition

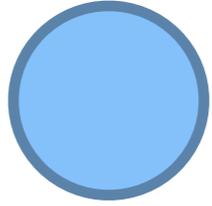
*A gesture is a motion of the body that contains information
[Kurtenbach]*

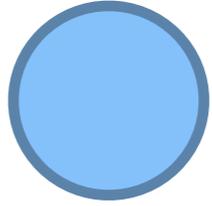


Definition

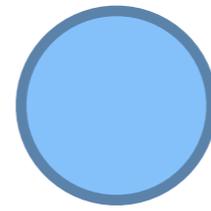
A gesture is a motion of the body that contains information
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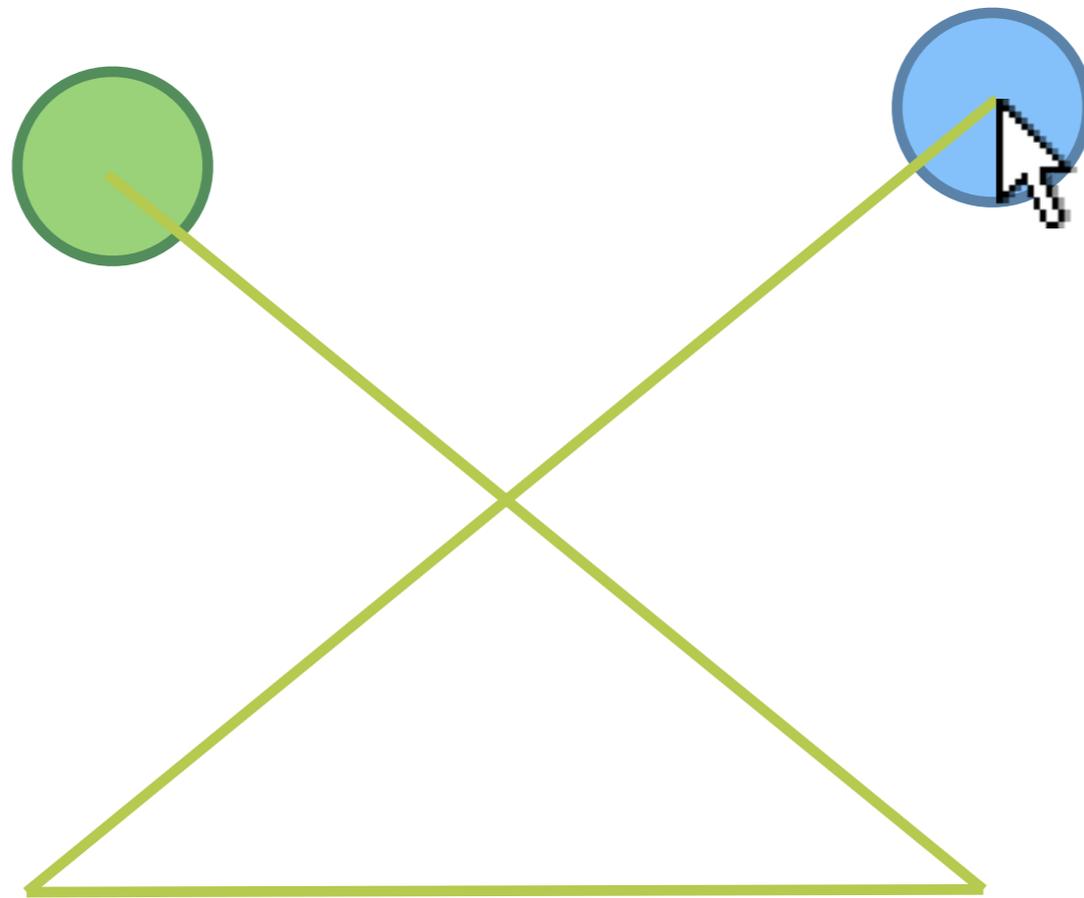




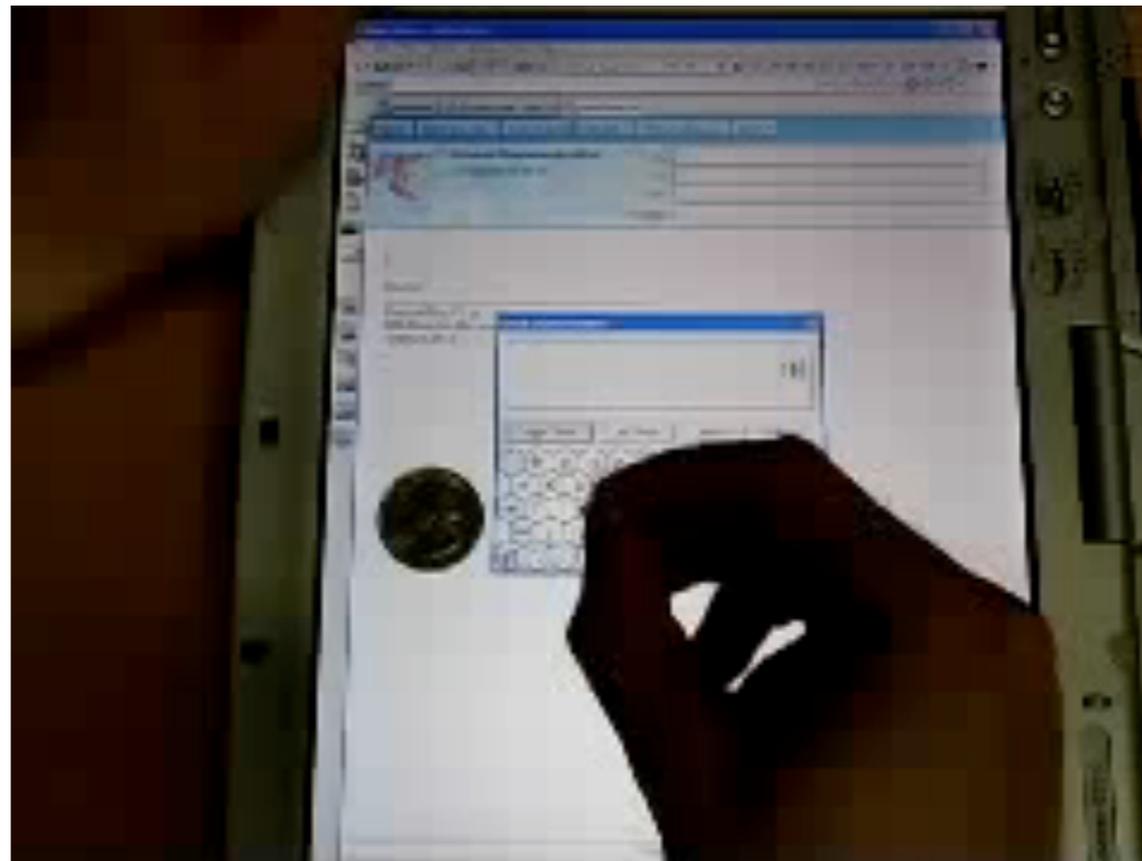




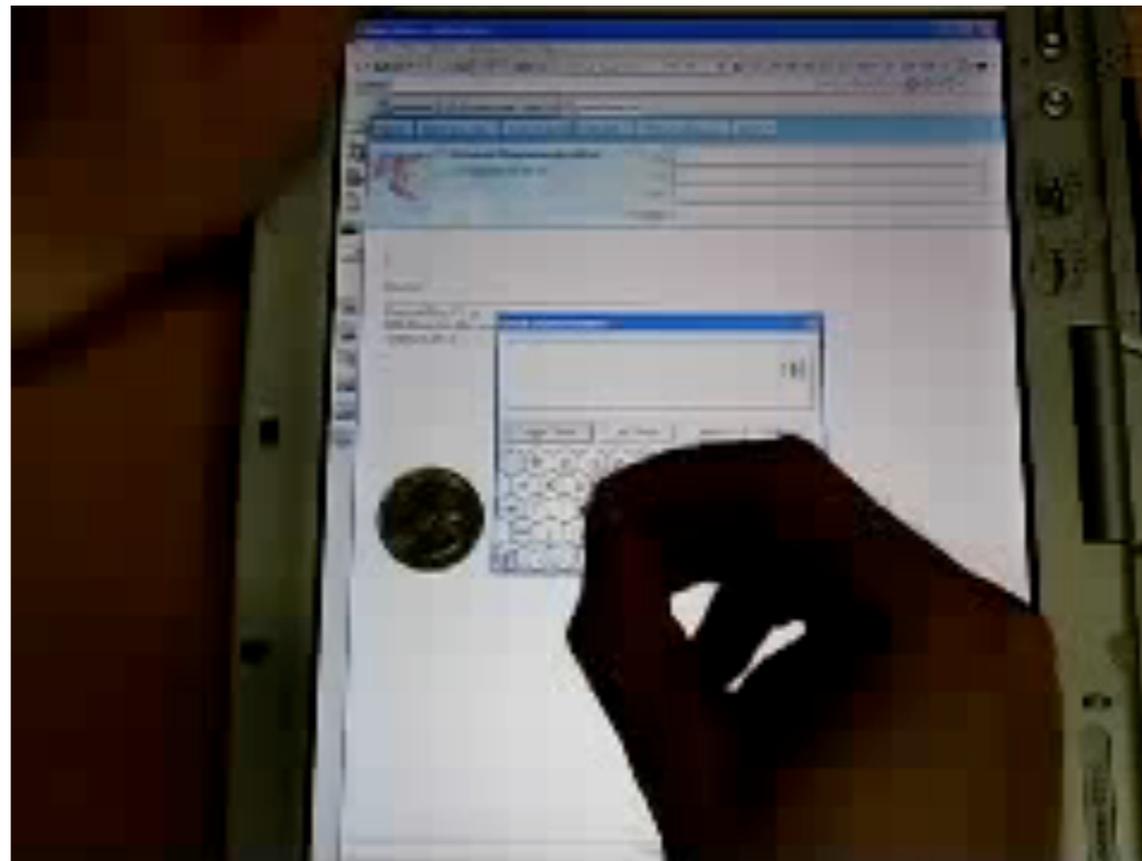




Shark 2004/Shapewriter 2007



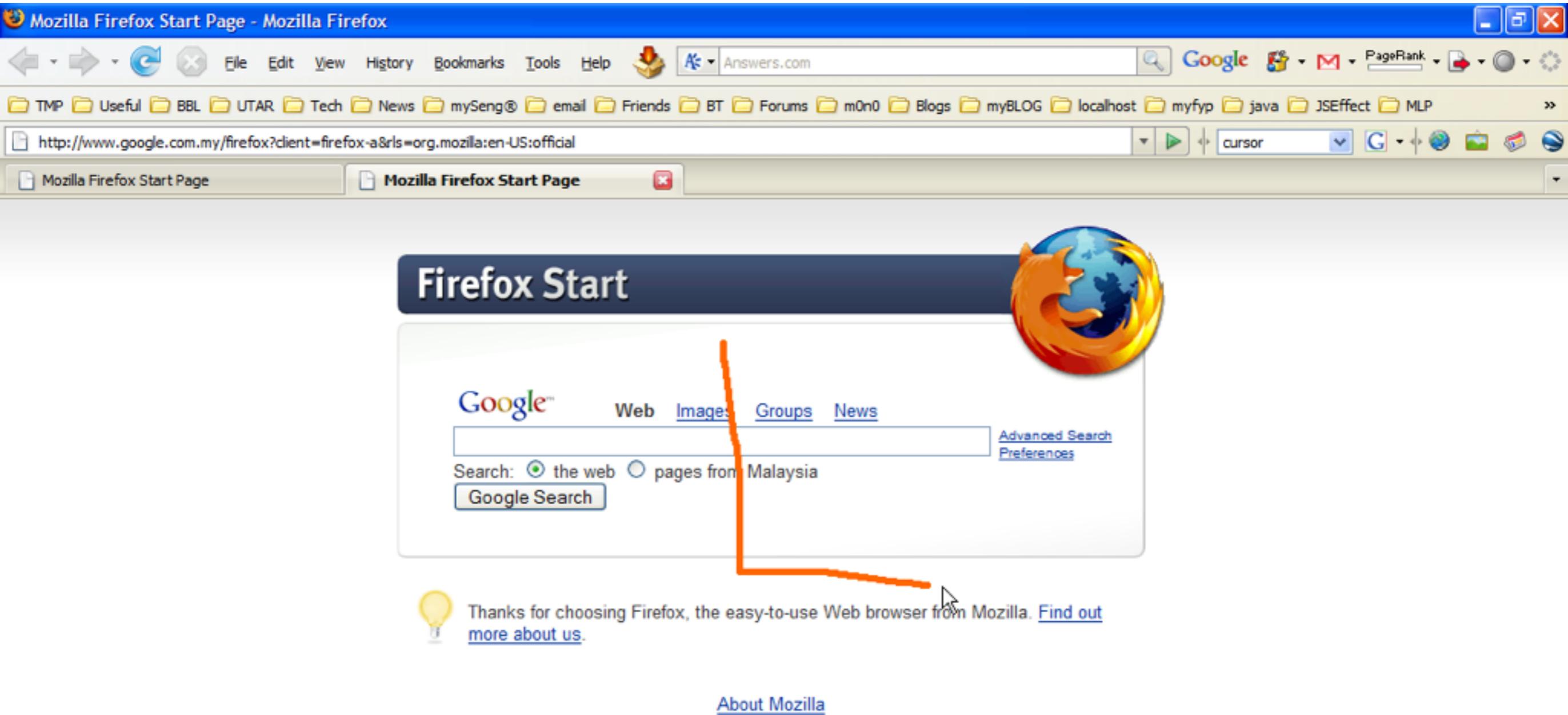
Shark 2004/Shapewriter 2007



Pourquoi?

- Capitaliser sur les compétences de l'utilisateur [Kurtenbach et al. 94]
- Combiner la selection de commande et l'operation en une seule action [Buxton et al. 86]
- Apprentissage rapide et implicite
- Très étudié en IHM

Applications (Mouse Gestures)

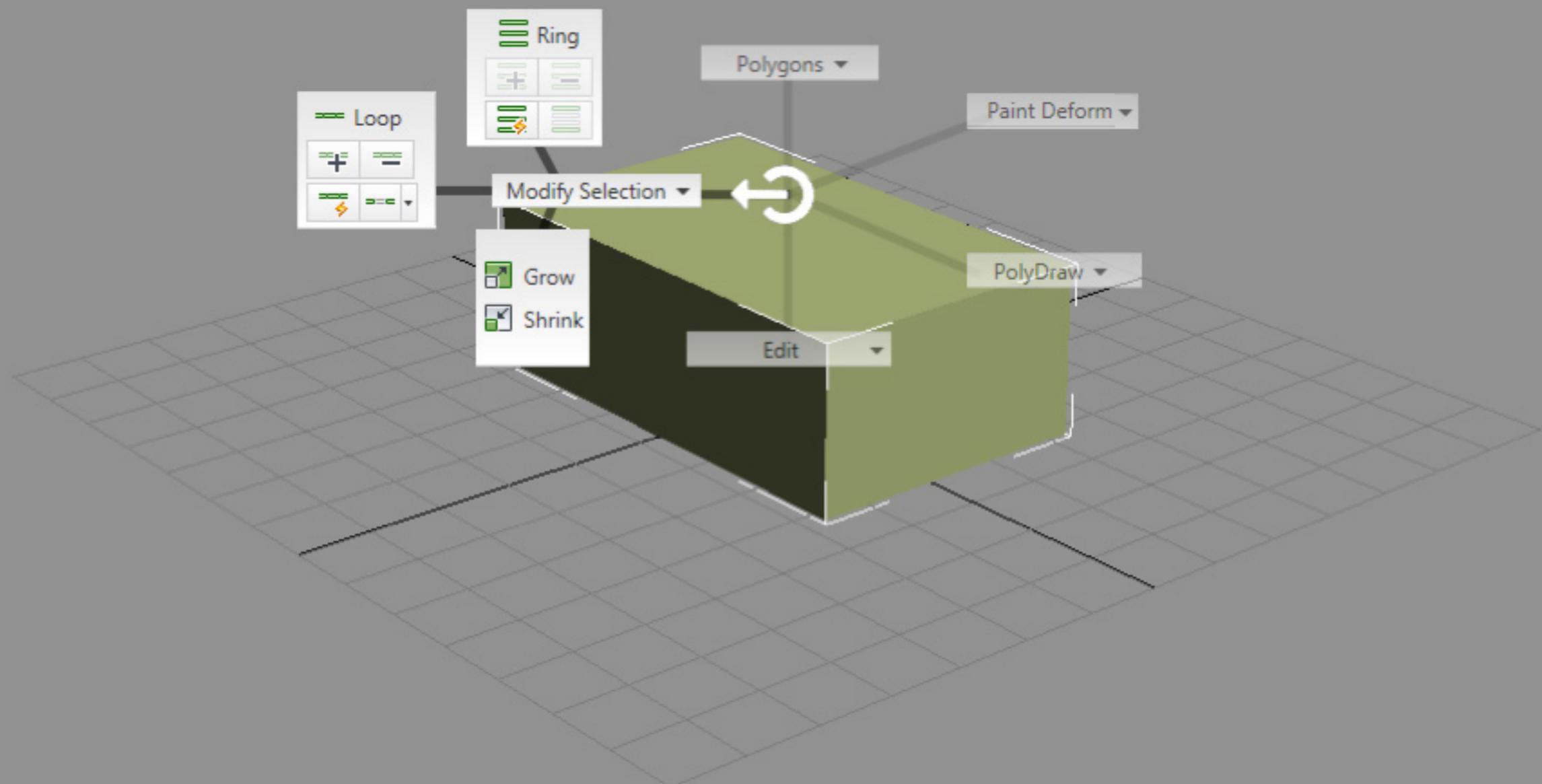


The image shows a screenshot of the Mozilla Firefox Start Page. The browser window title is "Mozilla Firefox Start Page - Mozilla Firefox". The address bar shows the URL "http://www.google.com.my/firefox?client=firefox-a&rls=org.mozilla:en-US:official". The page features a "Firefox Start" header with the Firefox logo. Below the header is a Google search interface with a search bar, "Google Search" button, and radio buttons for "the web" and "pages from Malaysia". A hand-drawn orange line starts from the search bar area and points to a mouse cursor hovering over the text "Find out more about us." in a message that says "Thanks for choosing Firefox, the easy-to-use Web browser from Mozilla. Find out more about us." Below this message is a link "About Mozilla".

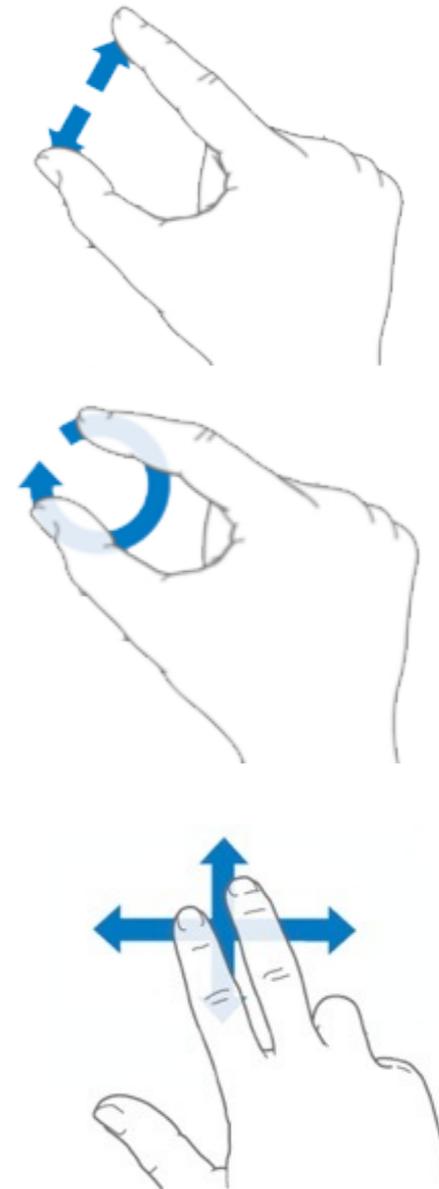


Applications (Mouse Gestures)

[+] [Perspective] [Smooth + Highlights]



Smartphone



Smartphone



Tabletop



Gaming



Gaming

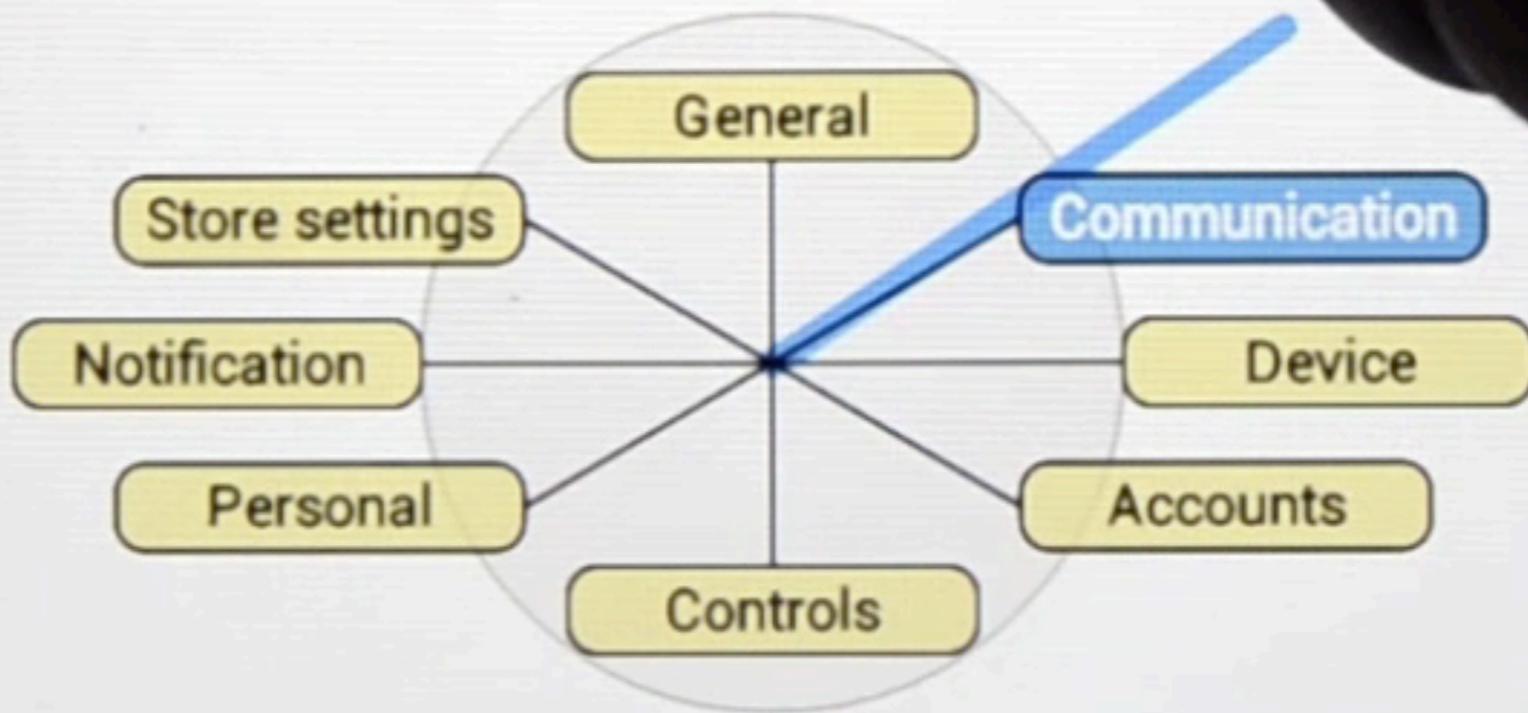


KINECT
SPORTS



Movies





Turn off

Turn off

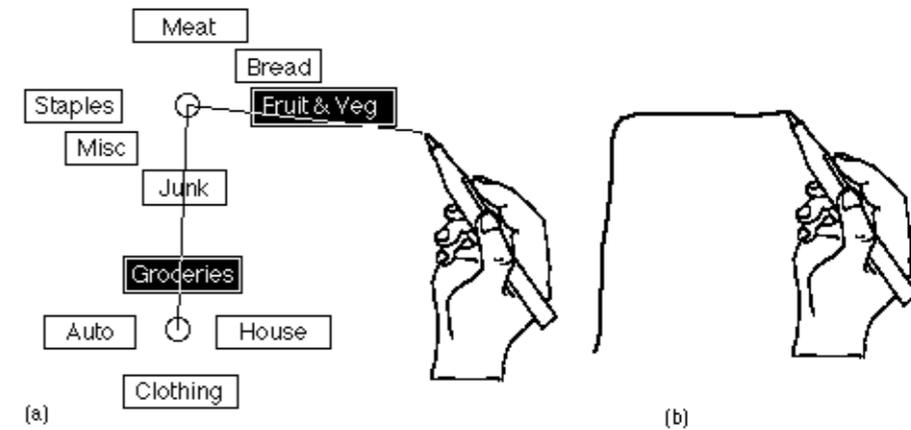
Brainstorming (2 minutes)
Qualités & Défauts & Propriétés (pourquoi?)

Vitesse & Precision

Apprentissage & mémorisation

Satisfaction

Autres ?



Vitesse & Precision

- + Layout circulaire (réduit la distance moyenne)
- + Indépendant à la distance (tolérance à l'exécution)
- + Mode expert (Raccourcis)

Apprentissage & Memorisation

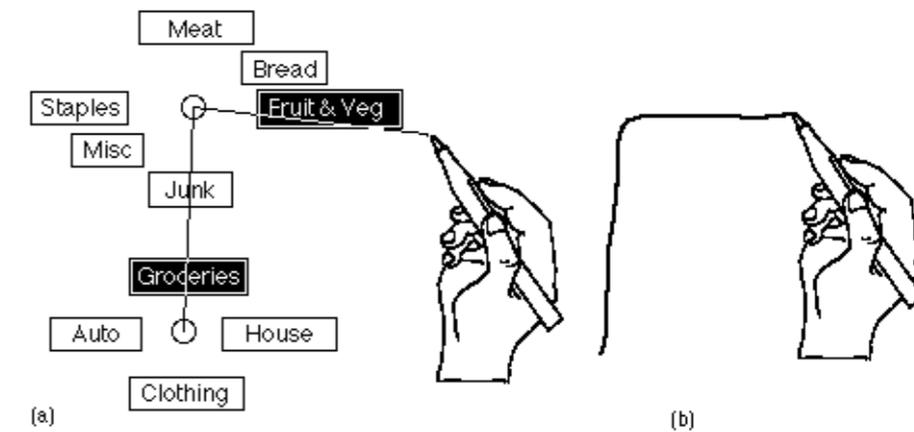
- + Mémoire spatiale (orientation)
- + Mémoire musculaire (transition fluide)
- + Association sémantique possible (ouvrir / fermer)

Satisfaction

- + Interaction gestuelle "appréciée"

Autres

- + En place
- + *Eyes-free* selection (selection possible sans regarder)
- **Nombre de commandes (profondeur :3 / largeur : 8)**
- **Espace requis**

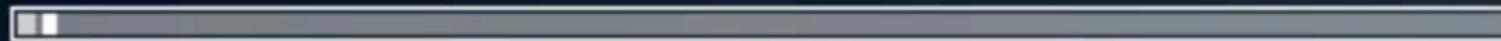


Demo of Marking Menus Versus Linear Menus

Autodesk Research



00:00

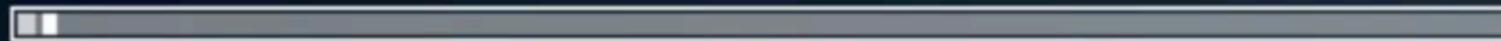


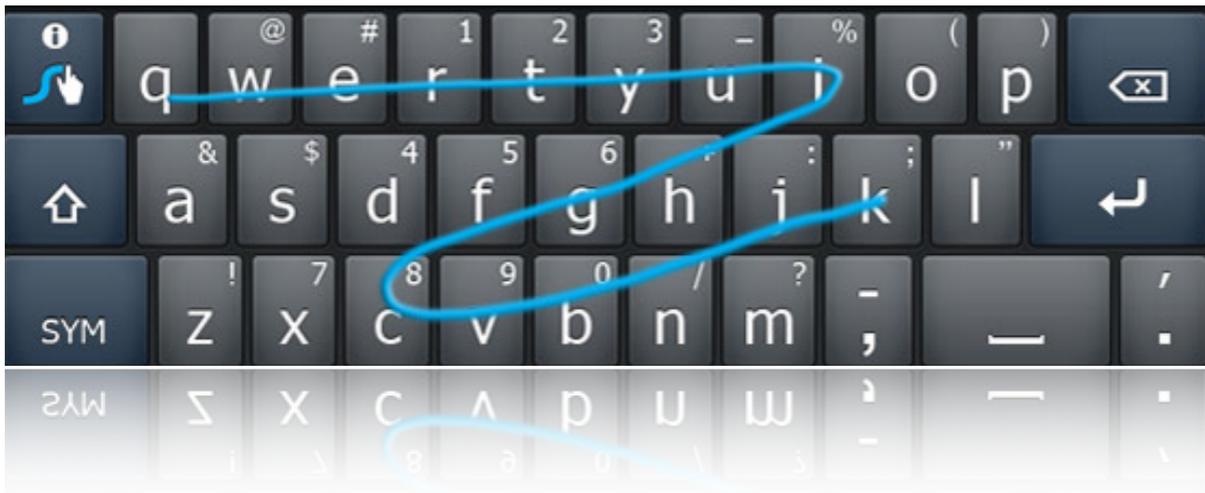
Demo of Marking Menus Versus Linear Menus

Autodesk Research



00:00

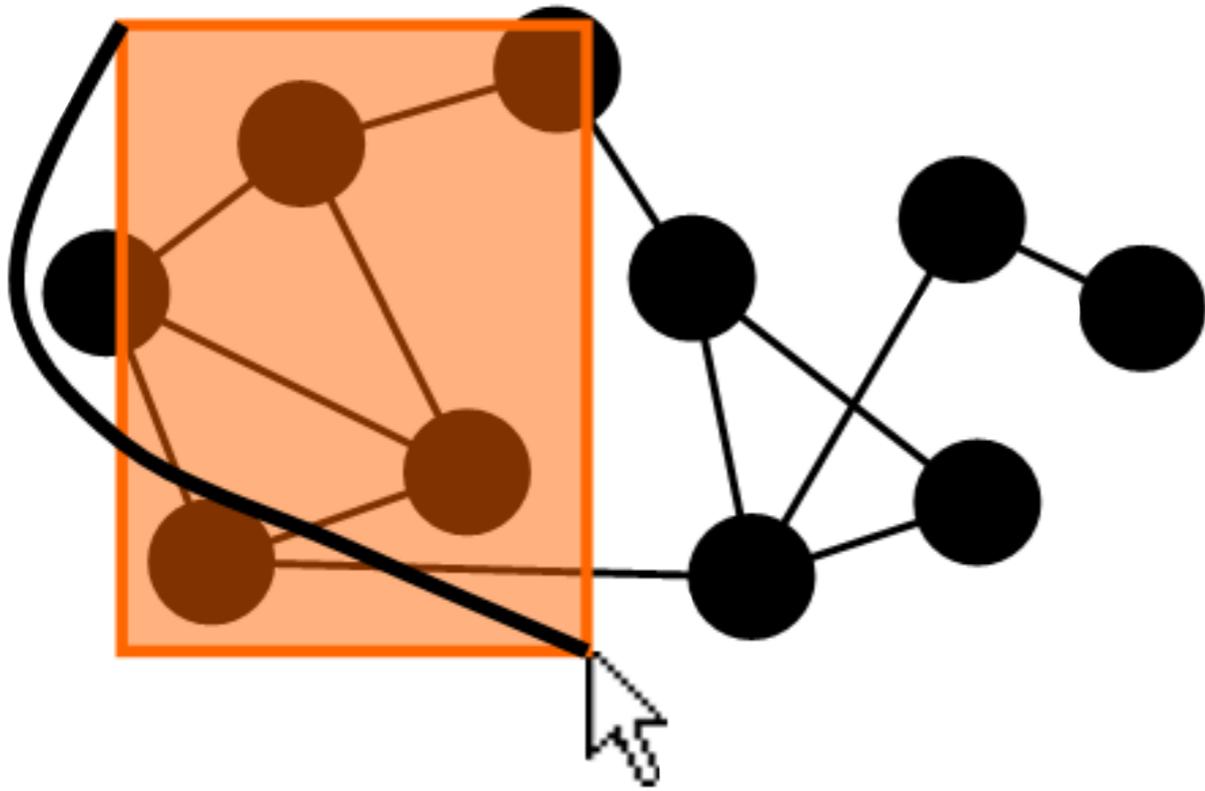




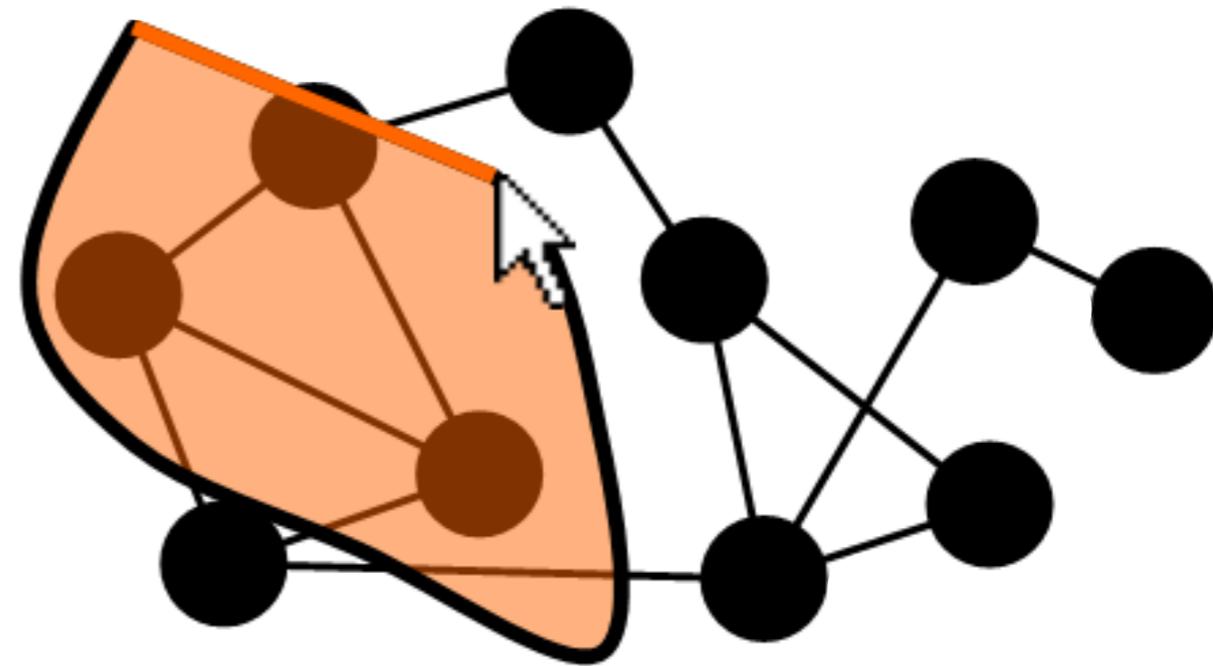
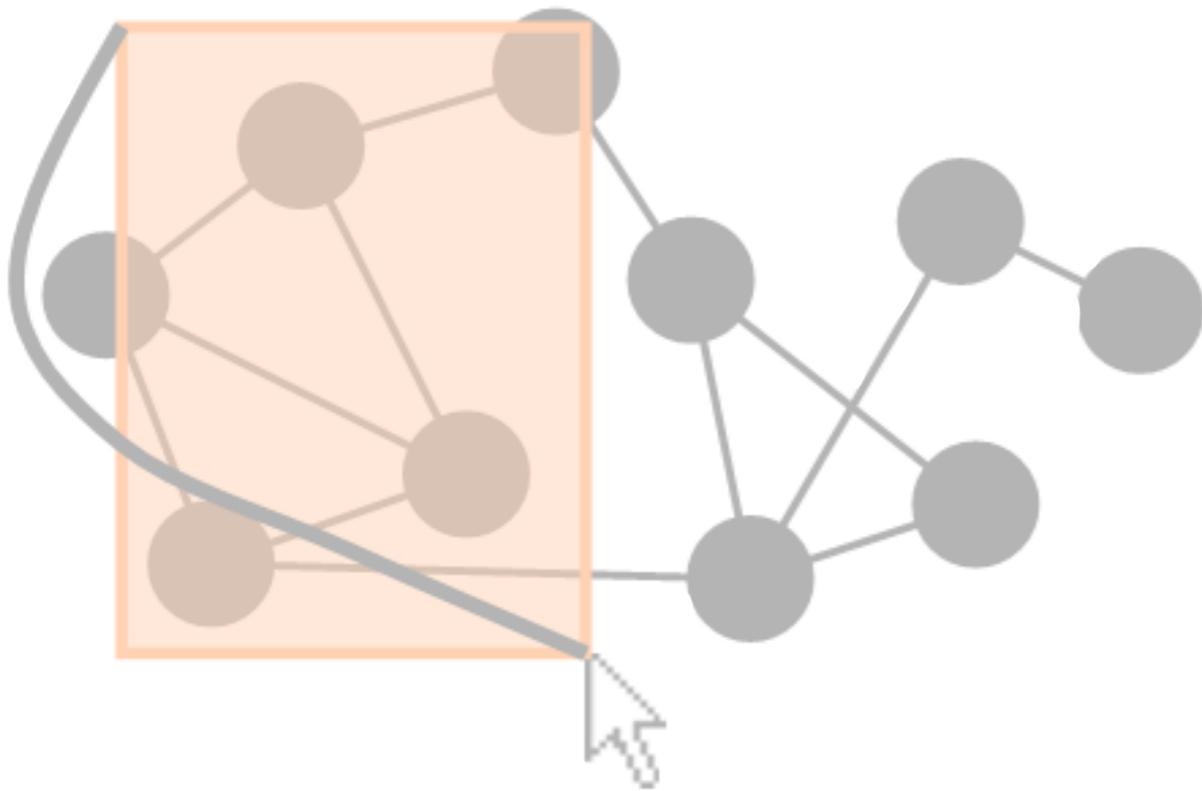
Entrée de texte



Selection de commande

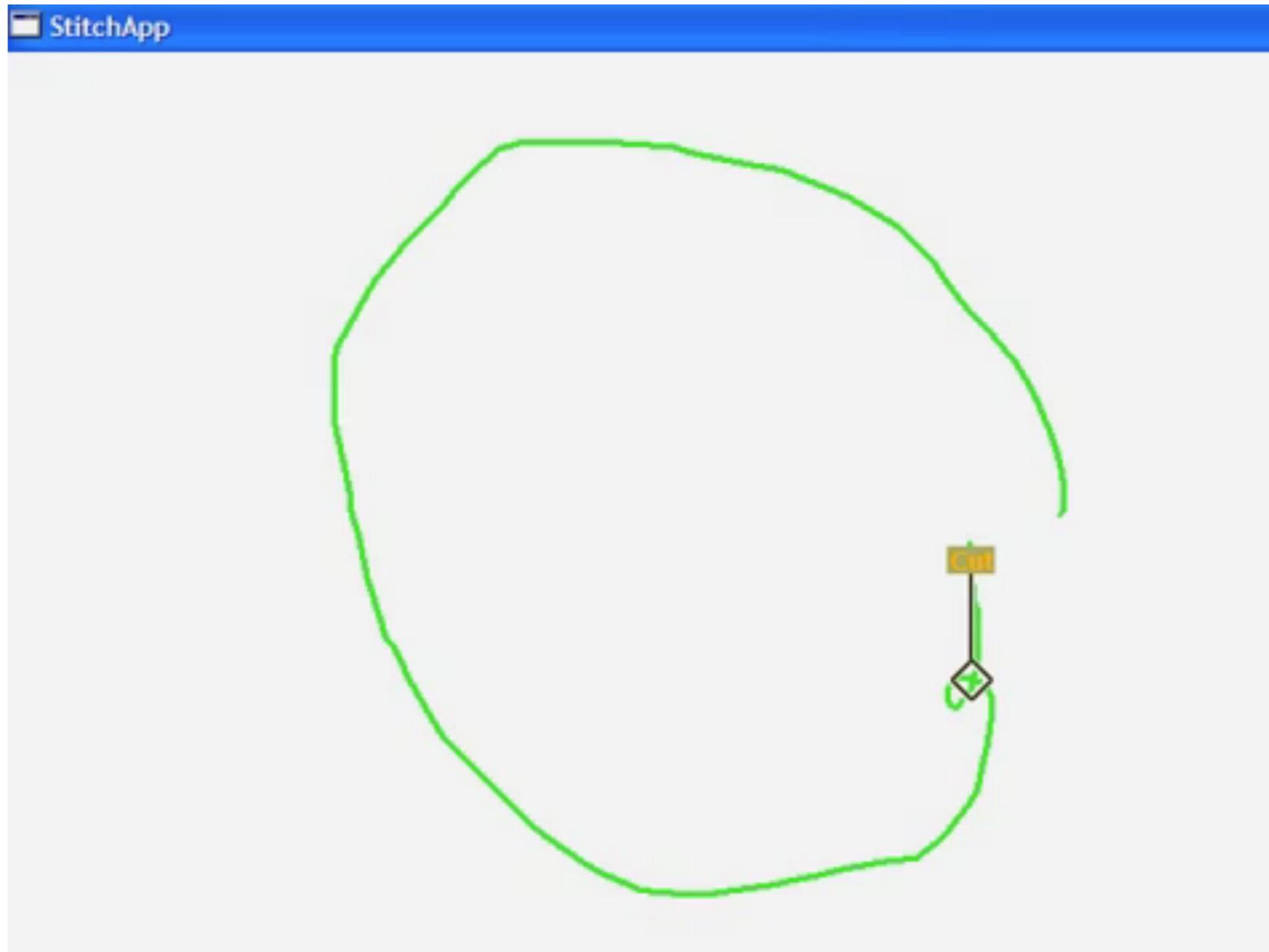


Sélection d'objets

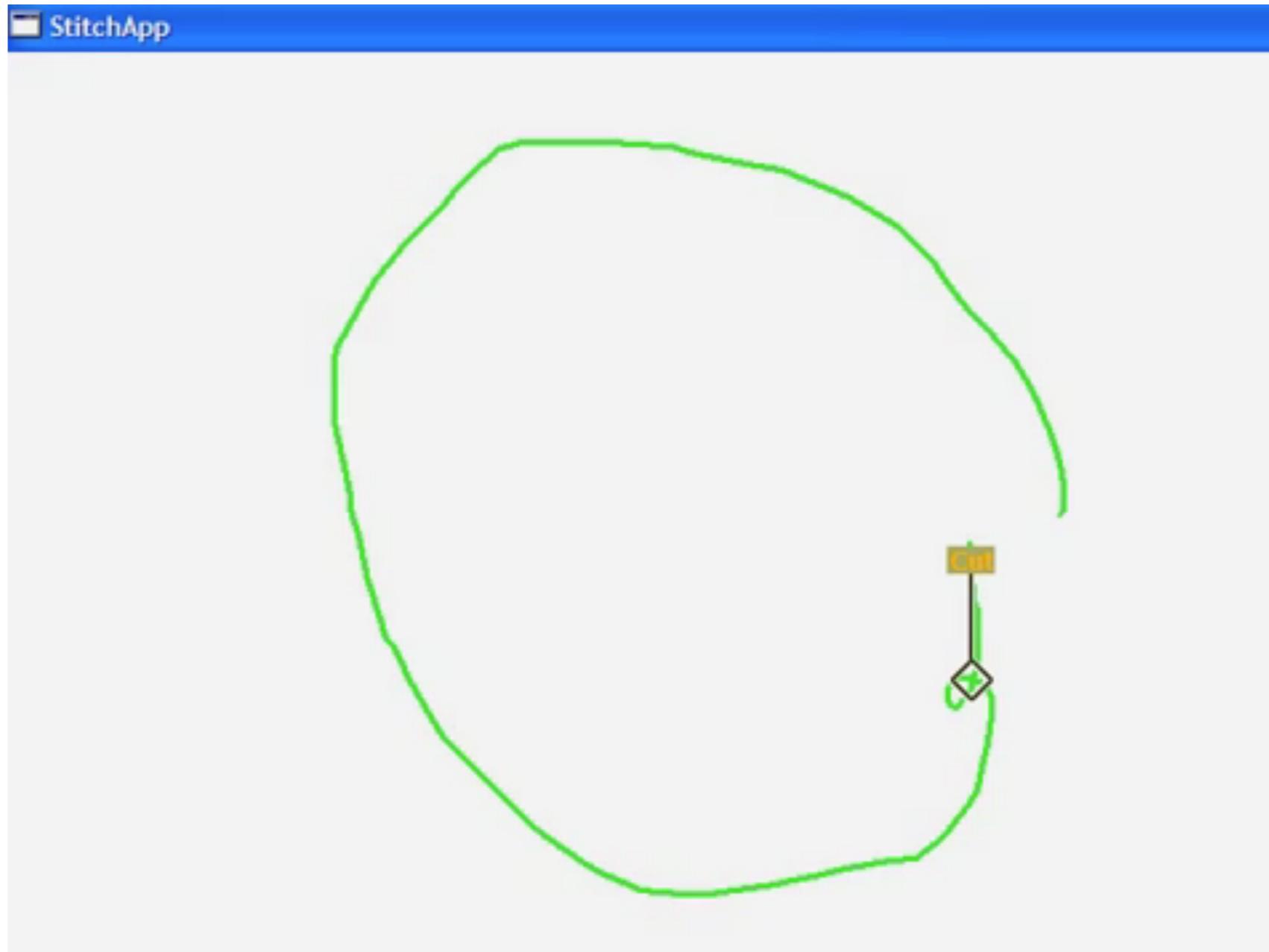


Sélection d'objets

Selection+commande en un seul geste

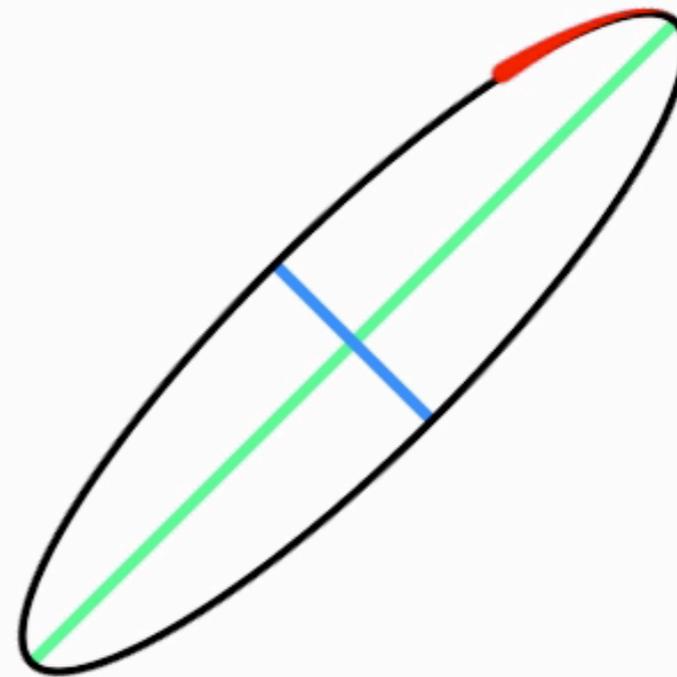


Selection+commande en un seul geste



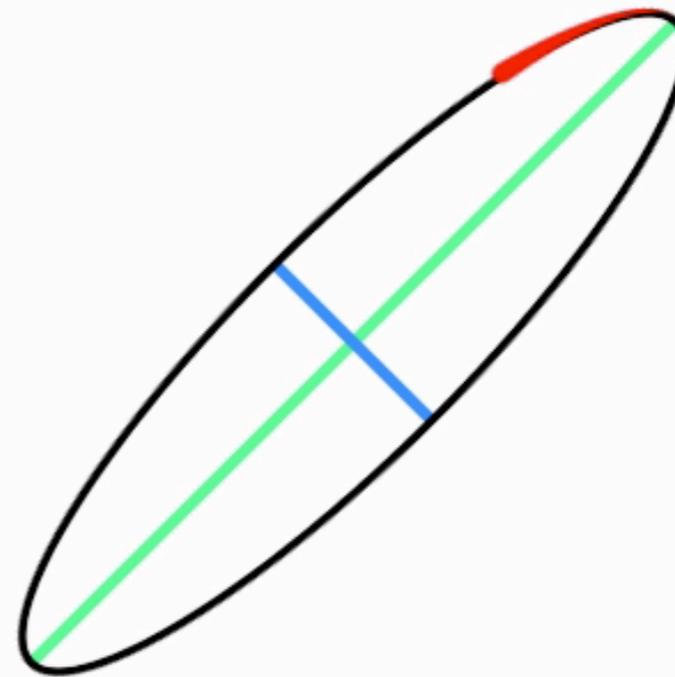
Oscillation elliptiques

6+1 dimensions



Oscillation elliptiques

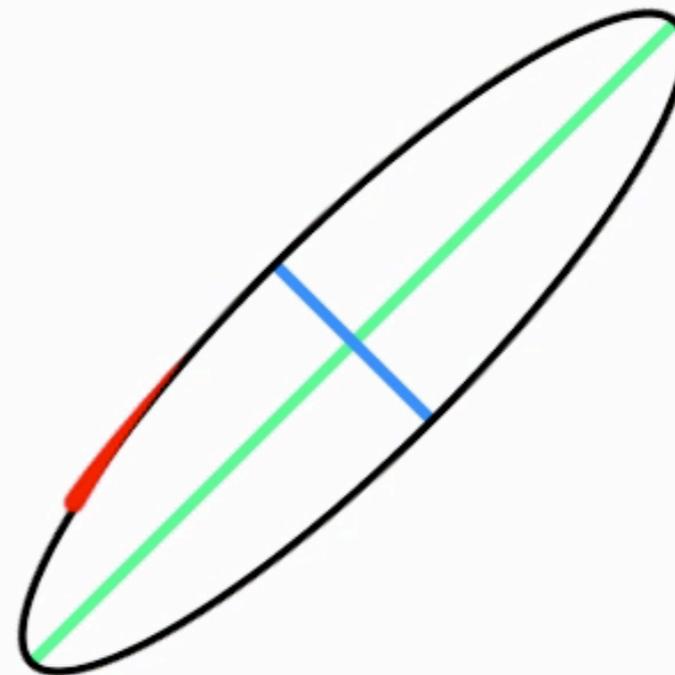
6+1 dimensions



Elliptic oscillatory gestures

6+1 dimensions

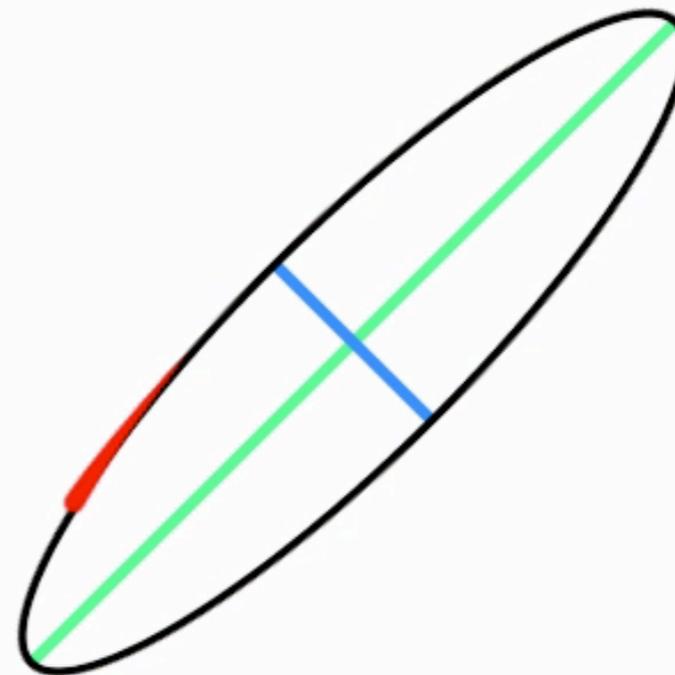
- Orientation



Elliptic oscillatory gestures

6+1 dimensions

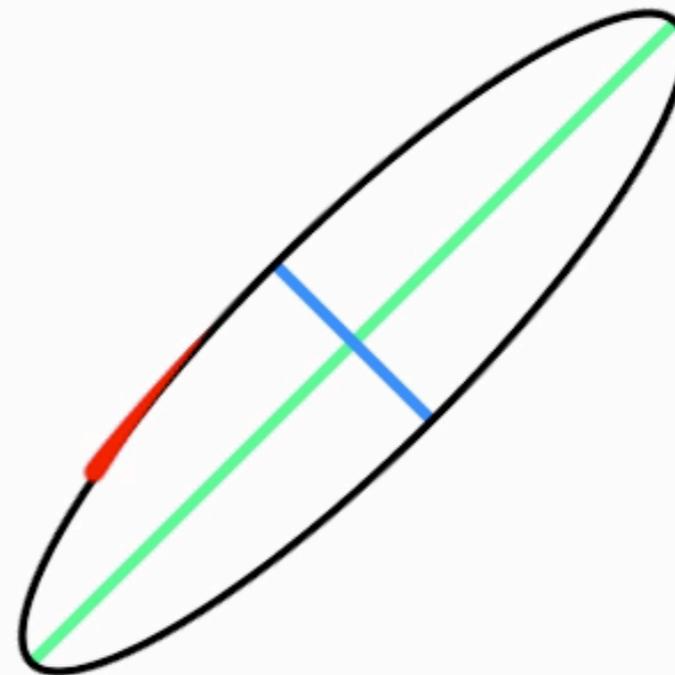
- Orientation



Elliptic oscillatory gestures

6+1 dimensions

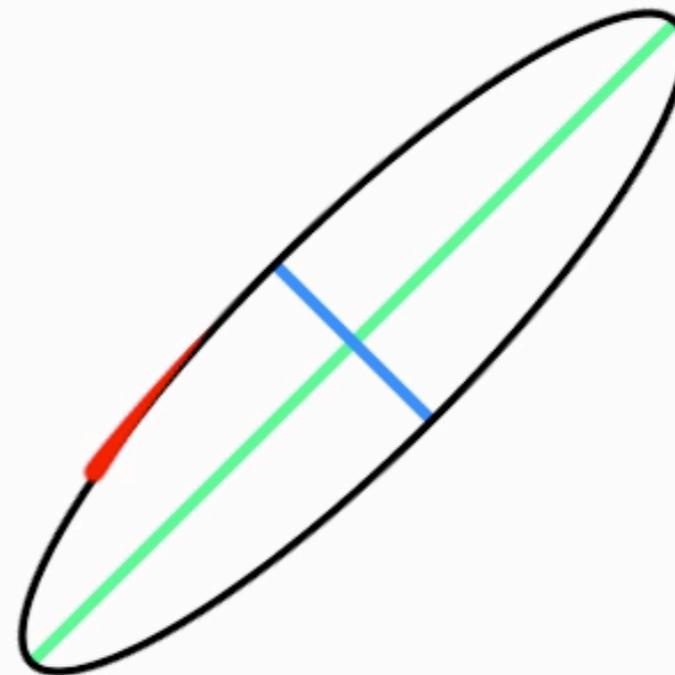
- Orientation
- Taille



Elliptic oscillatory gestures

6+1 dimensions

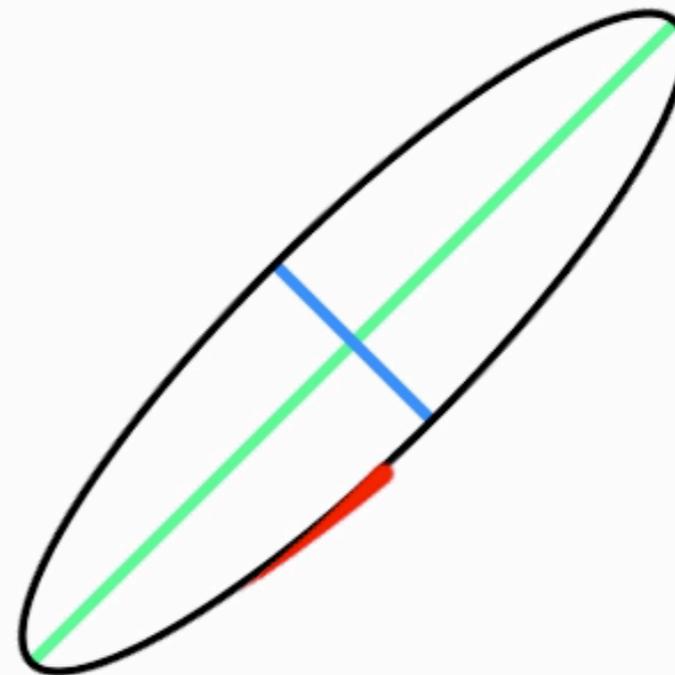
- Orientation
- Taille



Elliptic oscillatory gestures

6+1 dimensions

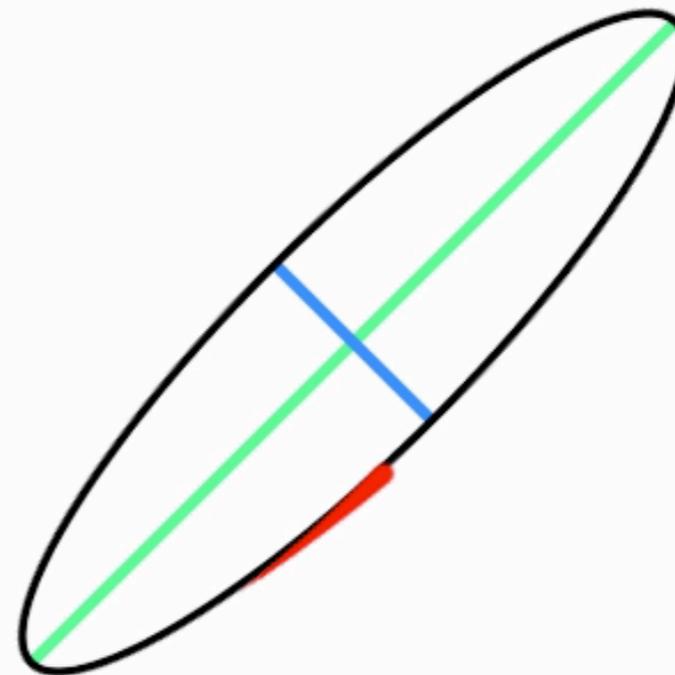
- Orientation
- Taille
- Excentricité



Elliptic oscillatory gestures

6+1 dimensions

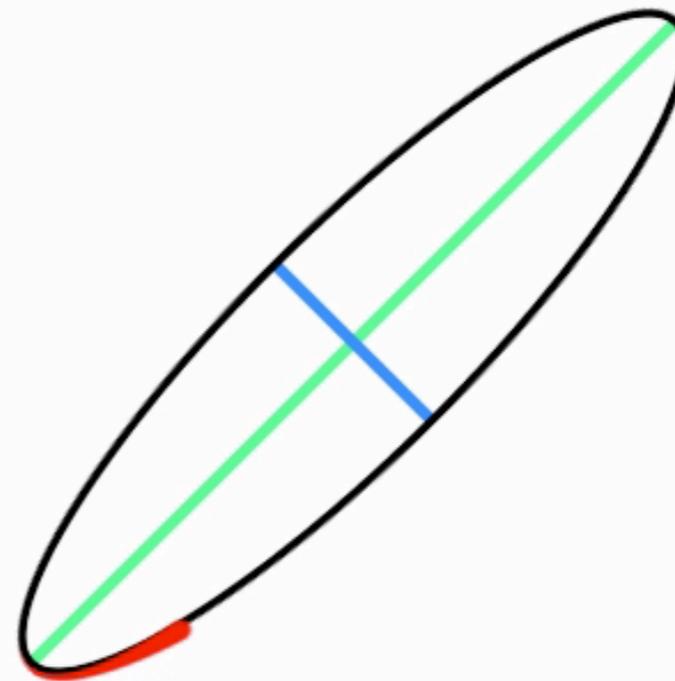
- Orientation
- Taille
- Excentricité



Elliptic oscillatory gestures

6+1 dimensions

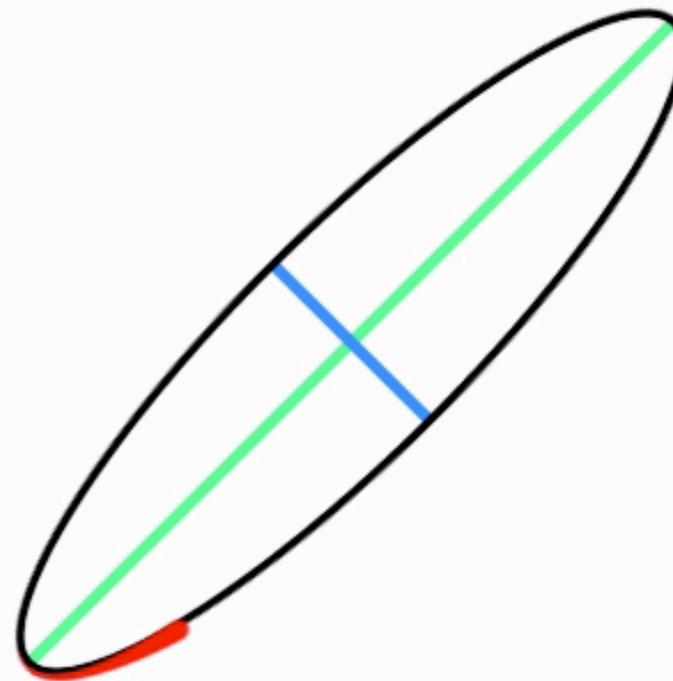
- Orientation
- Taille
- Excentricité
- **Position X**



Elliptic oscillatory gestures

6+1 dimensions

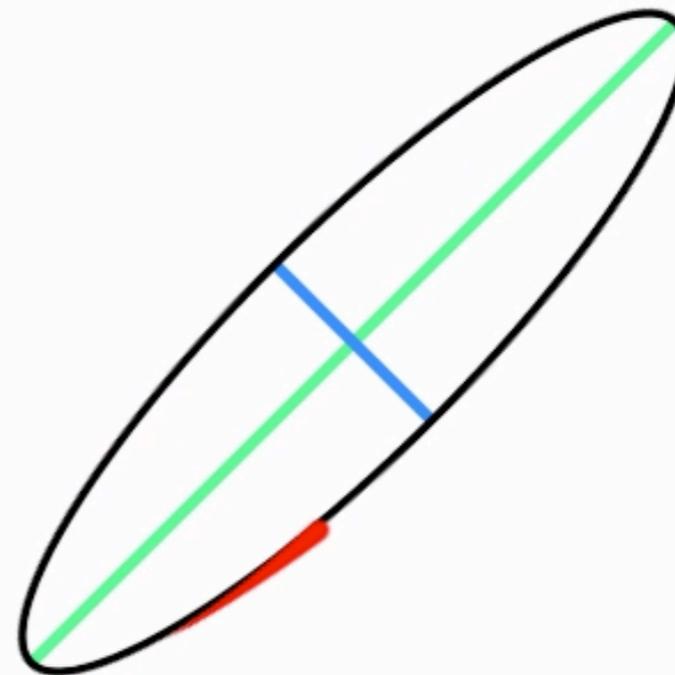
- Orientation
- Taille
- Excentricité
- **Position X**



Elliptic oscillatory gestures

6+1 dimensions

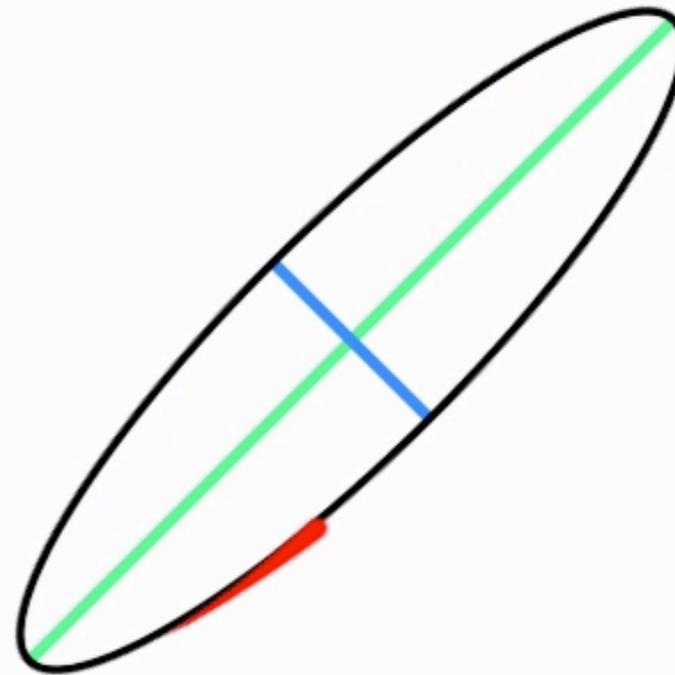
- Orientation
- Taille
- Excentricité
- Position X
- **Position Y**



Elliptic oscillatory gestures

6+1 dimensions

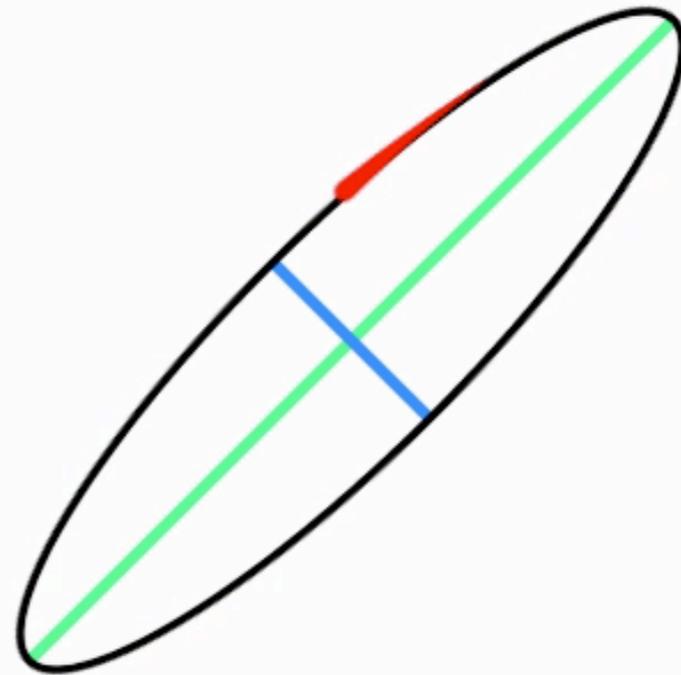
- Orientation
- Taille
- Excentricité
- Position X
- **Position Y**



Elliptic oscillatory gestures

6+1 dimensions

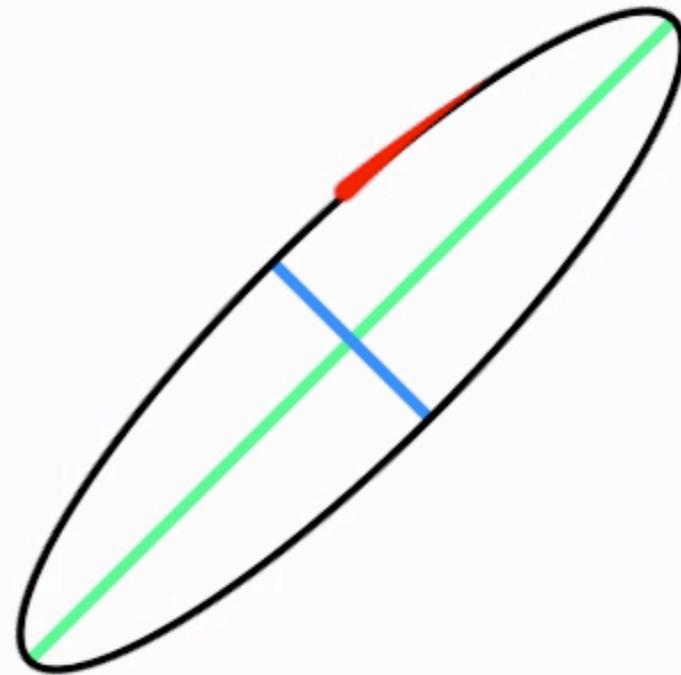
- Orientation
- Taille
- Excentricité
- Position X
- Position Y
- **Fréquence**



Elliptic oscillatory gestures

6+1 dimensions

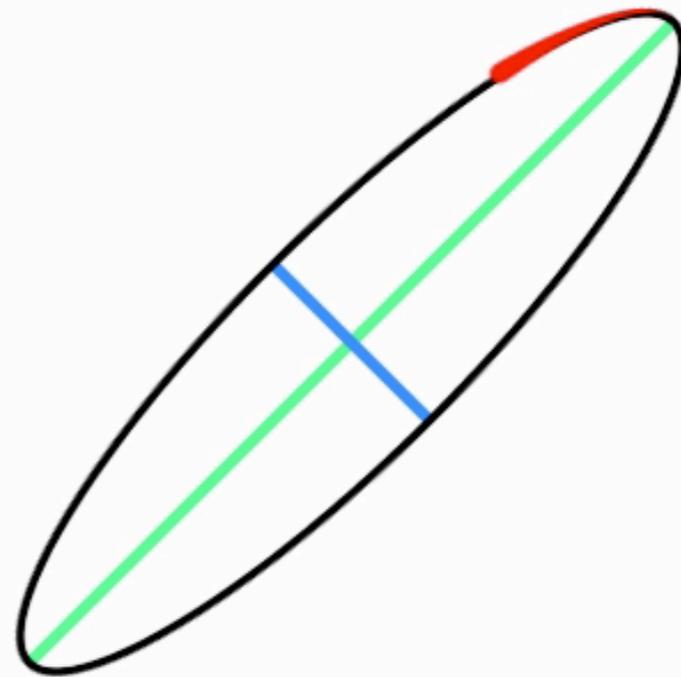
- Orientation
- Taille
- Excentricité
- Position X
- Position Y
- **Fréquence**



Elliptic oscillatory gestures

6+1 dimensions

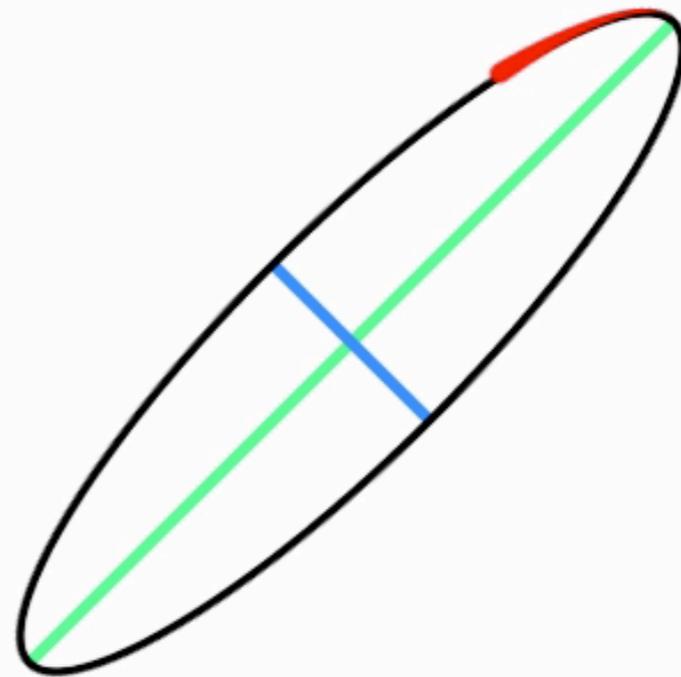
- Orientation
- Taille
- Excentricité
- Position X
- Position Y
- Fréquence
- **Rotation (CW or CCW)**



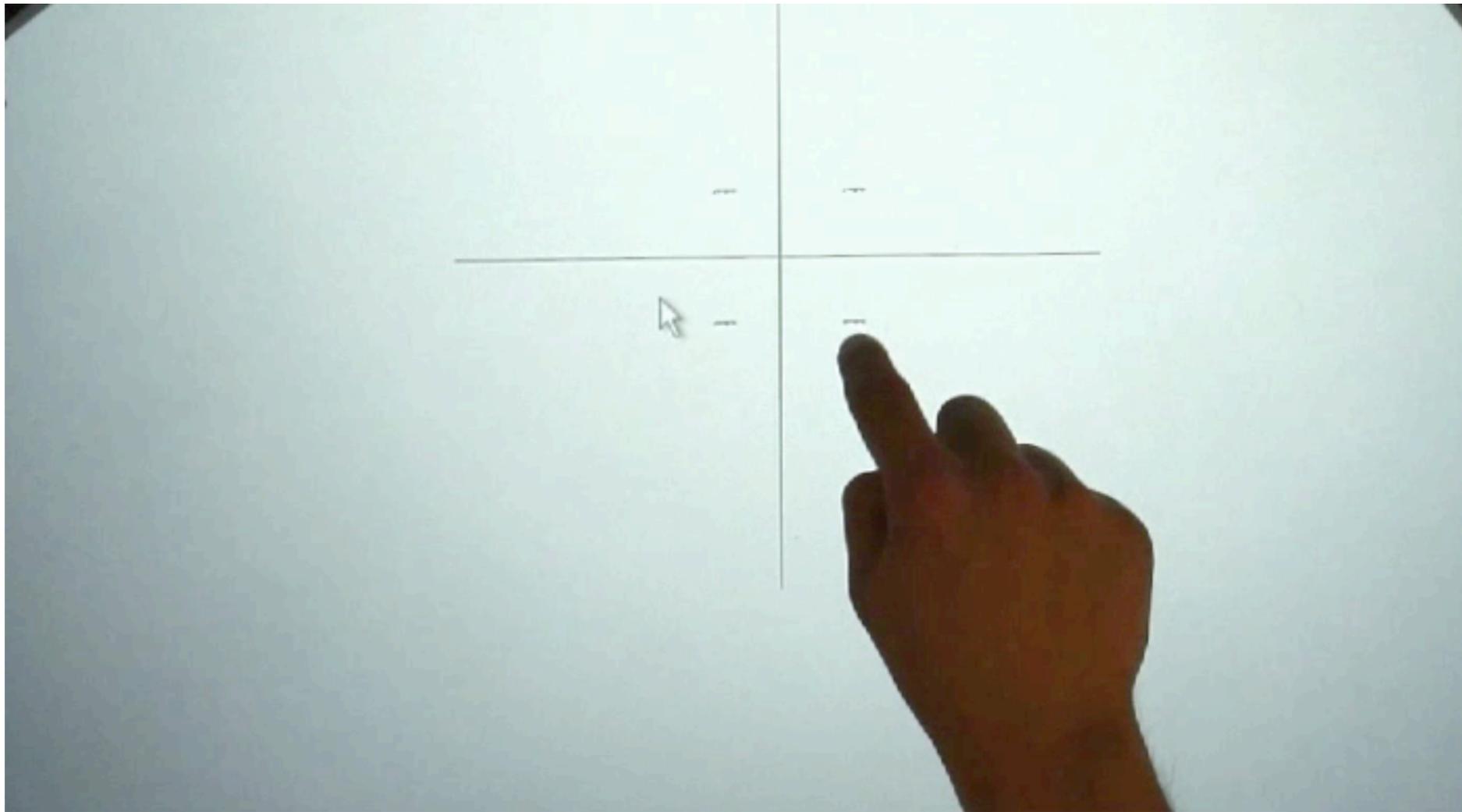
Elliptic oscillatory gestures

6+1 dimensions

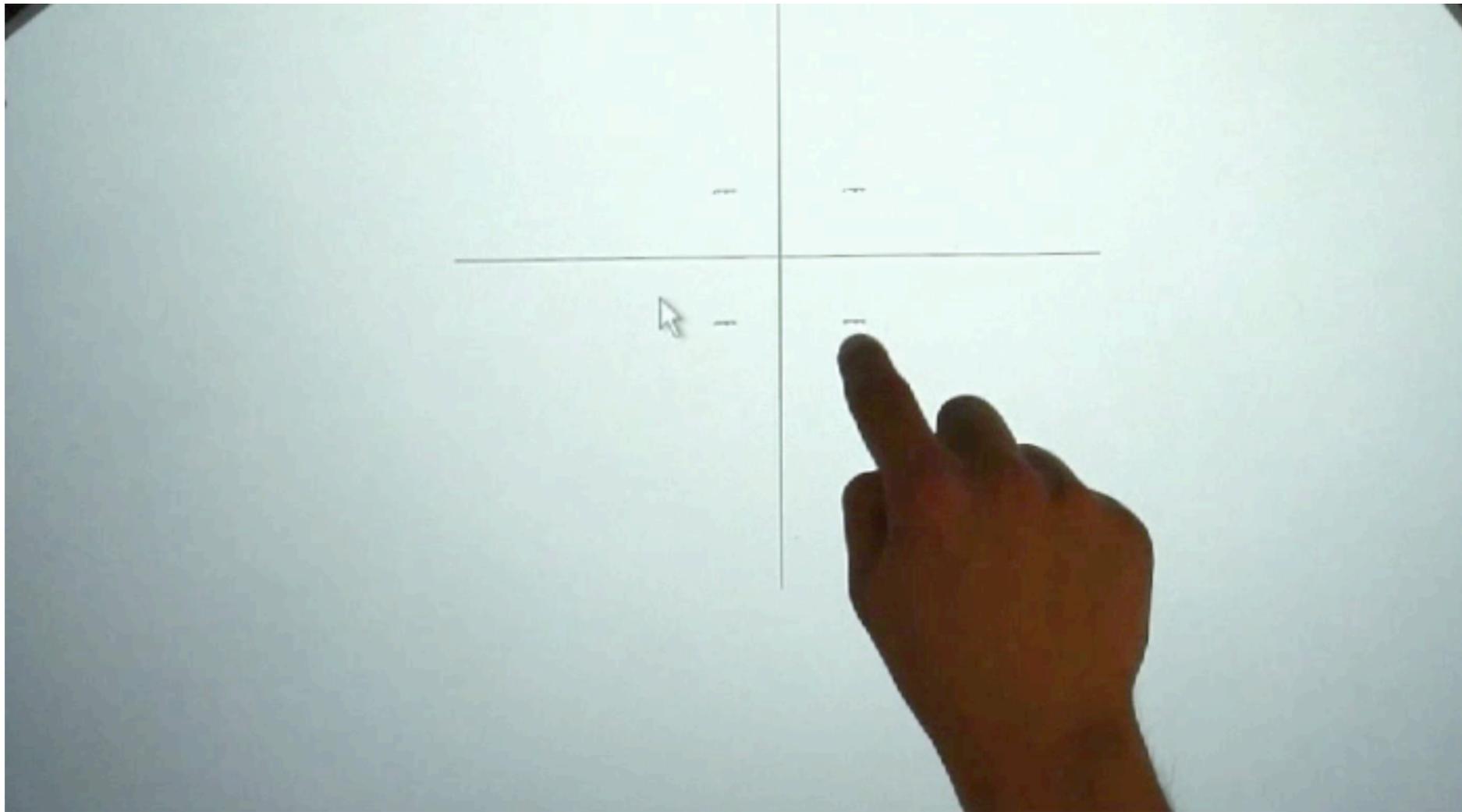
- Orientation
- Taille
- Excentricité
- Position X
- Position Y
- Fréquence
- **Rotation (CW or CCW)**



CycloZoom+



CycloZoom+



Typhoon Takes Aim at Northern Marianas



FWIW, about a decade ago a fishing boat offshore from my home town drew up a honking big WWII bomb. The Coast Guard decided that popping it was the safest solution, which they did in an empty prairie reachable by an inland waterway. Everyone for miles around felt their windows rattle, and no one knew what it was until the news carried the story later.

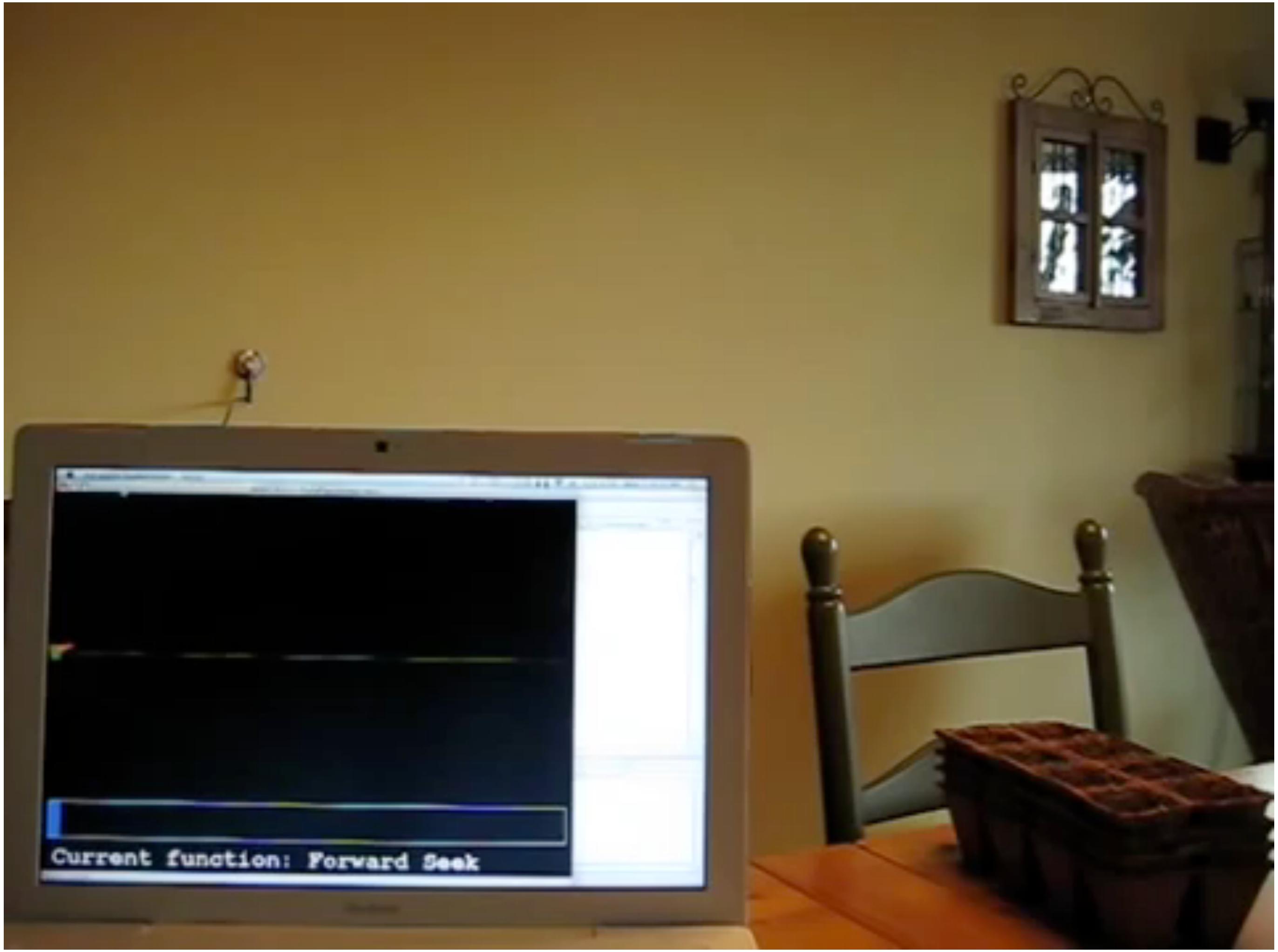
In the past, says Lee, countries had their own scientific facilities, and "could choose to work alone or together. But with ITER, or a new global linear collider, the world can only build one. The only way is to put our resources together." The deadlock, Lee adds, "is not a problem of ITER negotiations. It's generic."

Typhoon Takes Aim at Northern Marianas

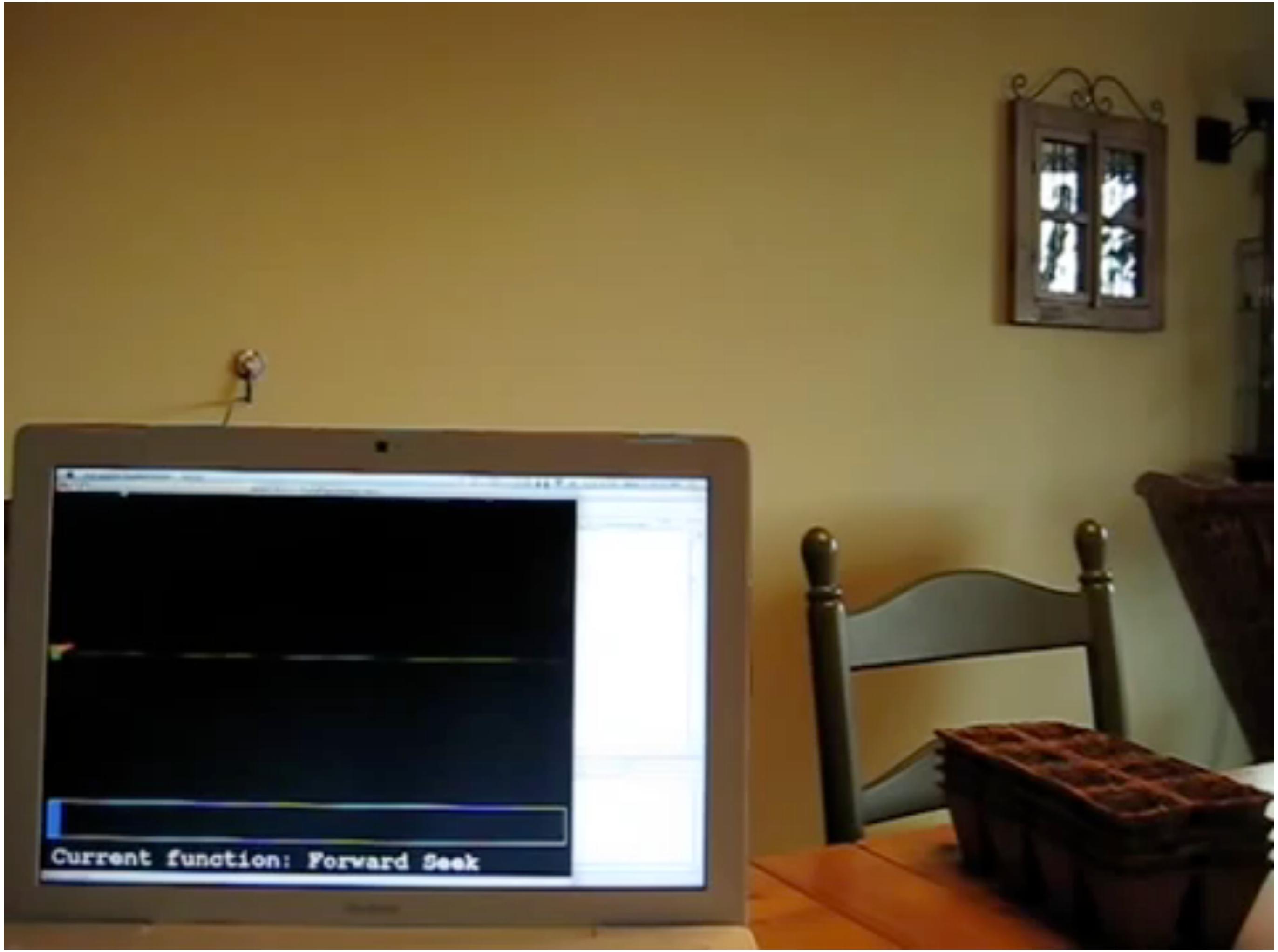


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Current function: Forward Seek



Current function: Forward Seek

Challenges

Choisir un set de gestes

Définir une association geste/commande

*Imagine that you are designer
You have a list of 24 commands and
You want to build a gestural interface*

Comment procéder ?

Create a gesture set

Symbolic gestures

self-mapping

Command 1

Command 2

Command 3

Command 4

Command 5

Command 6

Command 7

Command 8

Command 9

Command 10

Command 11

Command 12

Command 13

Command 14

Command 15

Command 16

Create a gesture set

Symbolic gestures

self-mapping

Command 1

Command 2

Command 3

Command 4

Command 5

Command 6

Command 7

Command 8

Command 9

Command 10

Command 11

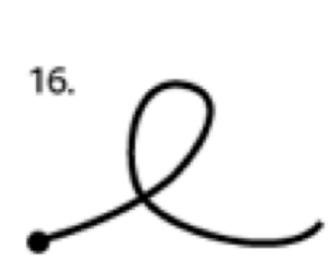
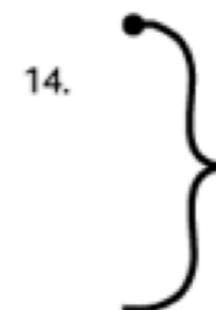
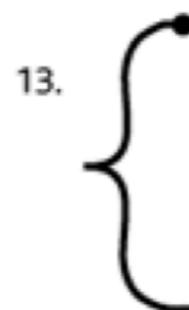
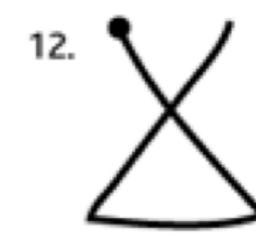
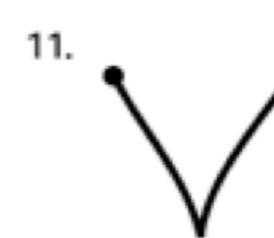
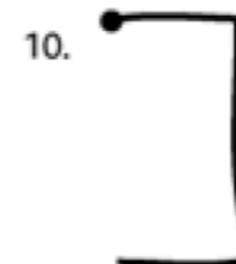
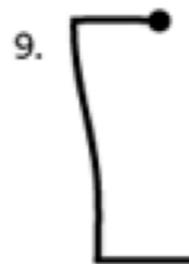
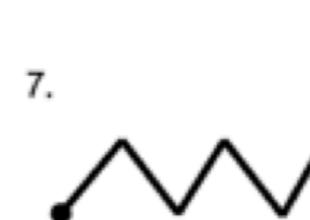
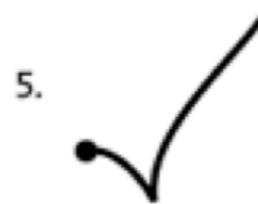
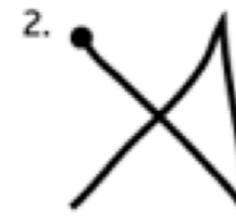
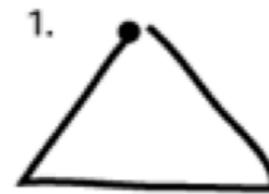
Command 12

Command 13

Command 14

Command 15

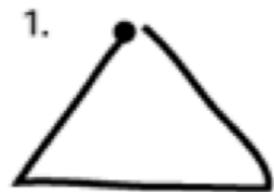
Command 16



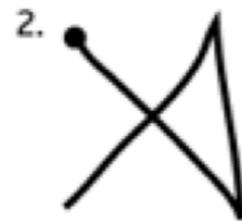
Create a gesture set

Symbolic gestures

self-mapping



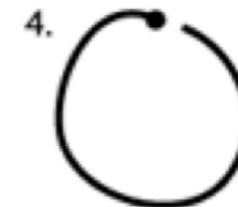
Command 1



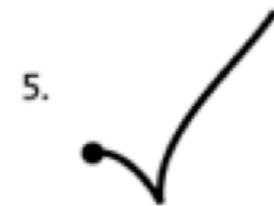
Command 10



Command 3



Command 16



Command 4



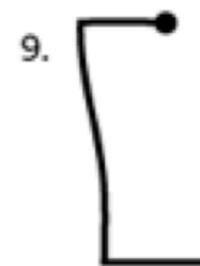
Command 2



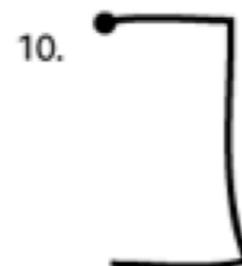
Command 11



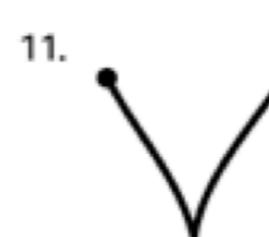
Command 15



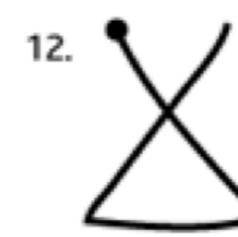
Command 8



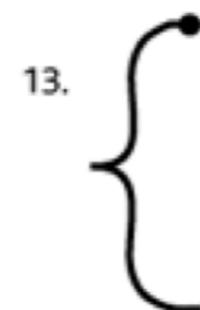
Command 12



Command 9



Command 6



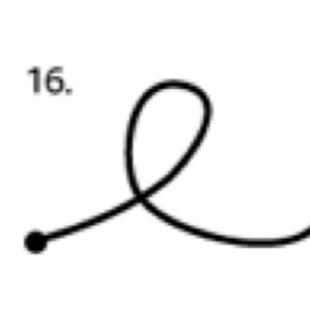
Command 14



Command 13



Command 7

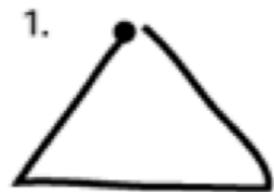


Command 5

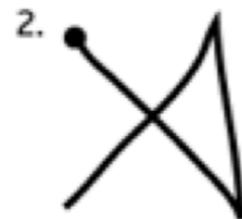
Create a gesture set

Symbolic gestures

self-mapping



Command 1



Delete



Command 3



Command 16



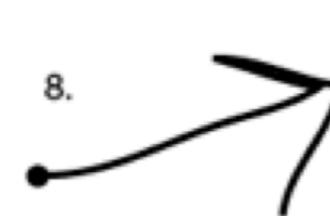
Command 4



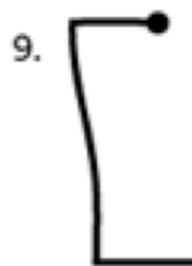
Command 2



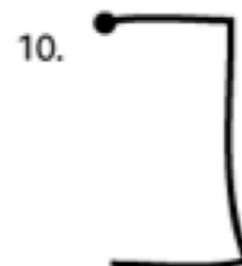
Command 11



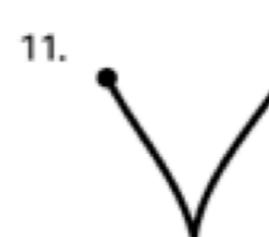
Next



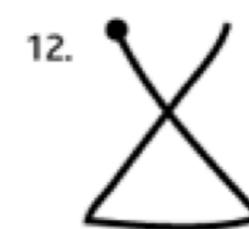
Command 8



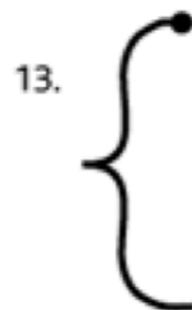
Command 12



Command 9



Command 6



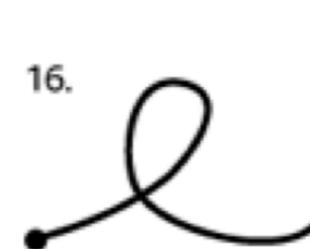
Command 14



Command 13



Add to favorite

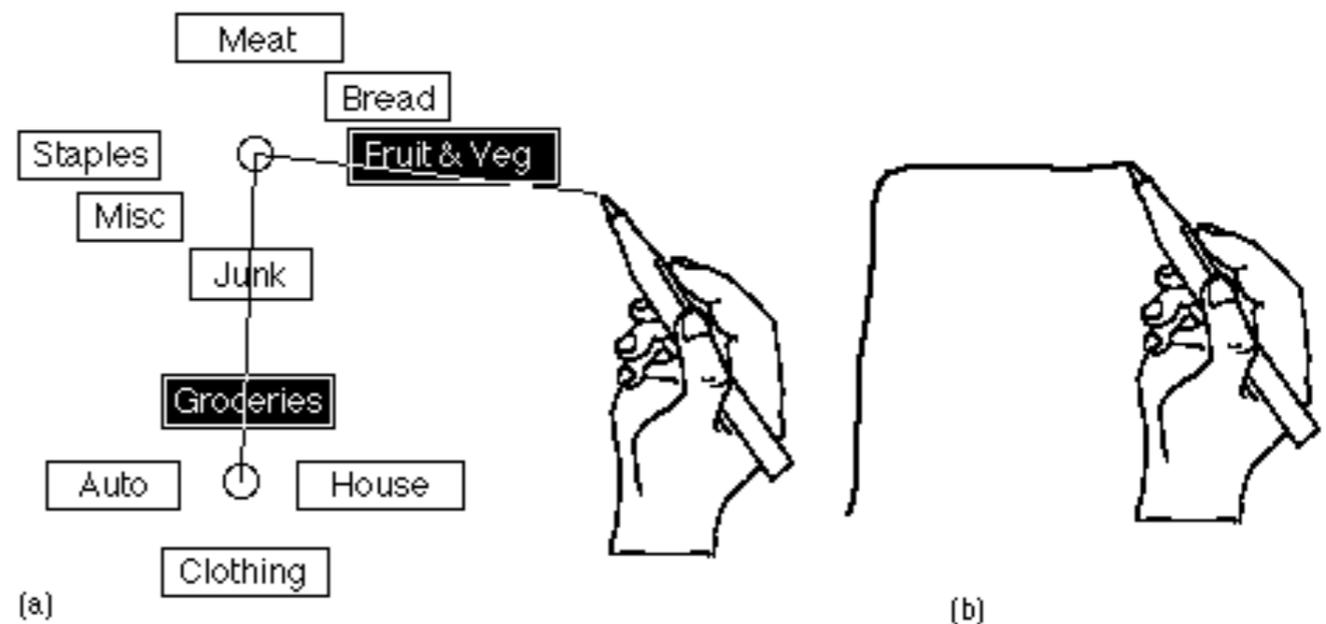


Command 5

Create a gesture set

Abstract Gestures

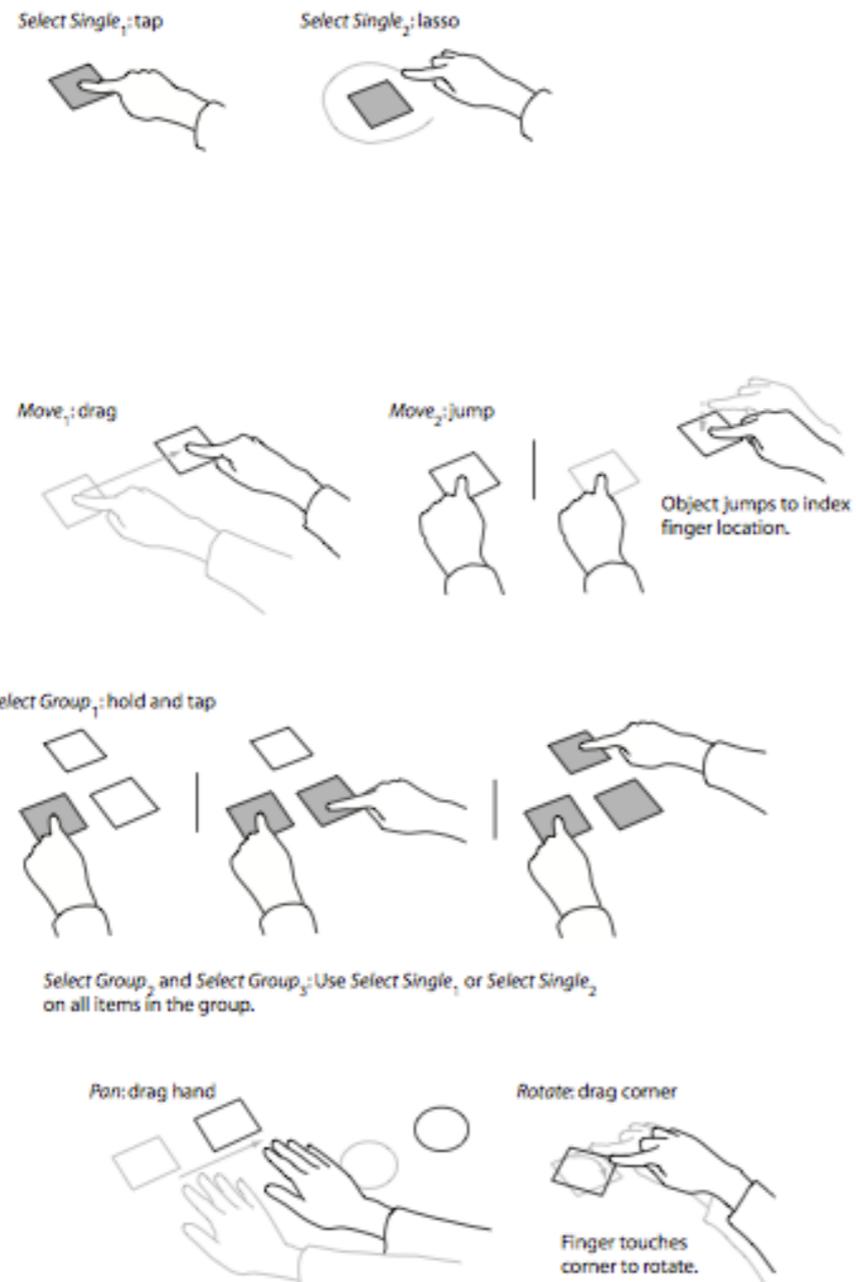
- ▶ + Organization
- ▶ + Accuracy
- ▶ - Gesture shape suggests no meaning



Define a mapping

User defined gestures

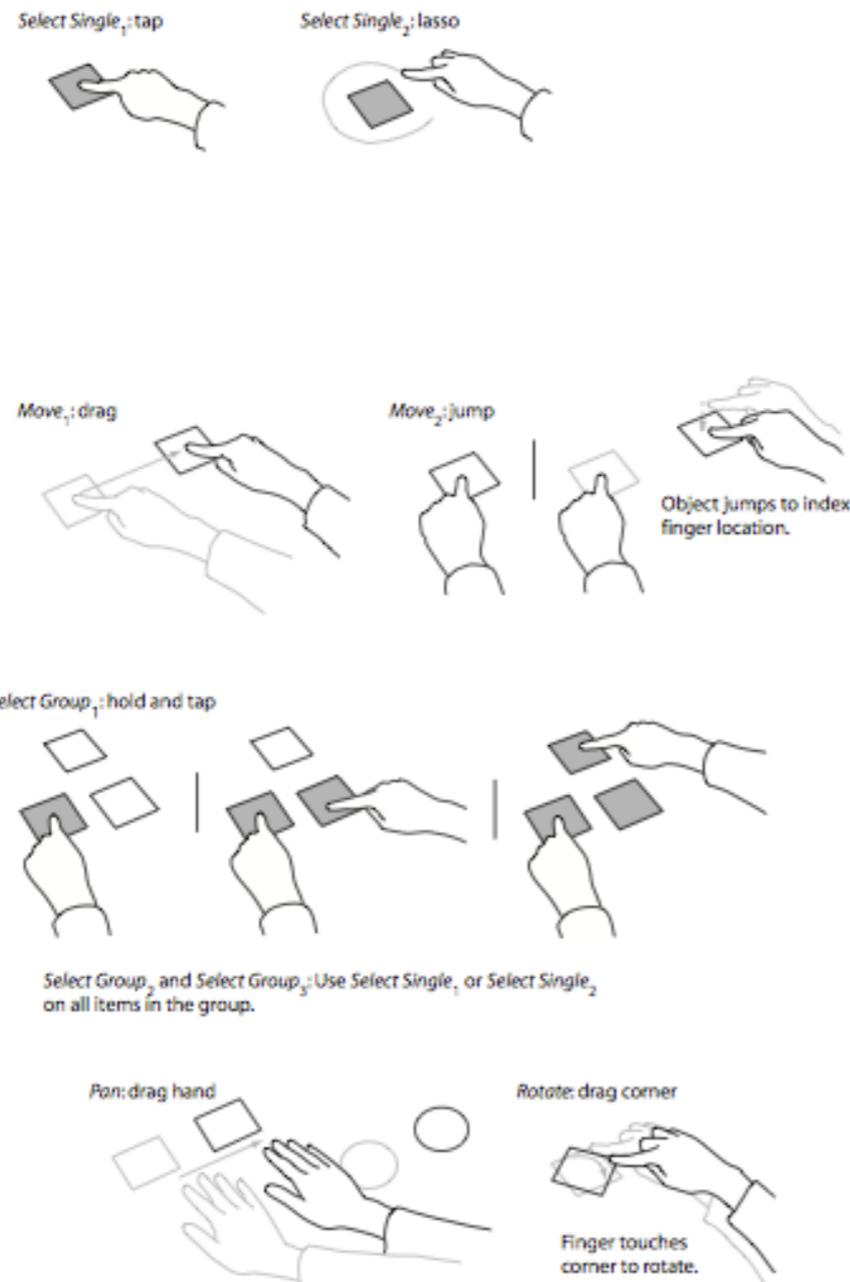
Capture “natural” mappings



Define a mapping

User defined gestures

Capture “natural” mappings

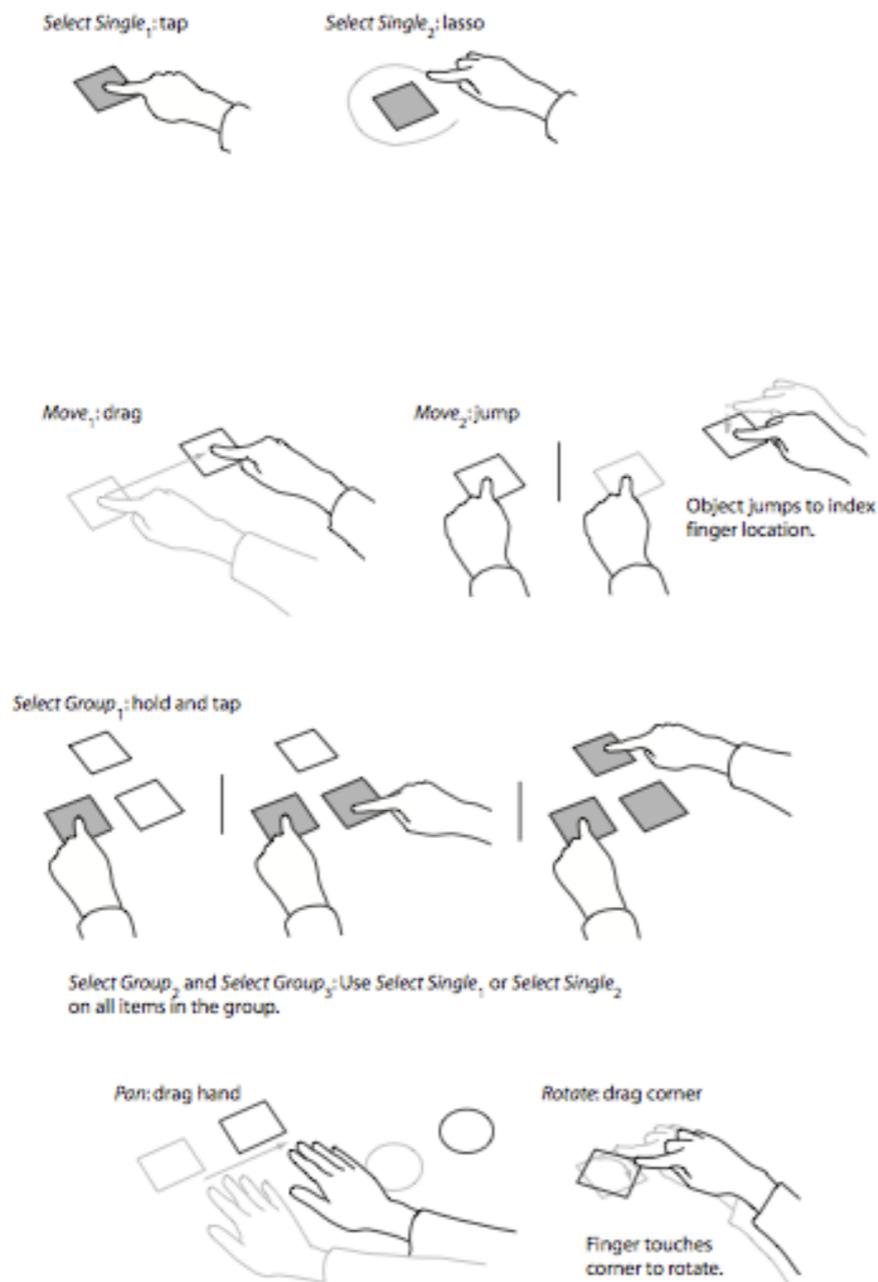


command
accept
minimize
previous
select single
help
next
open
move
cut
rotate
shrink
delete
pan
undo
select group
menu
paste
reject
enlarge
zoom in
duplicate
zoom out

Define a mapping

User defined gestures

Capture “natural” mappings

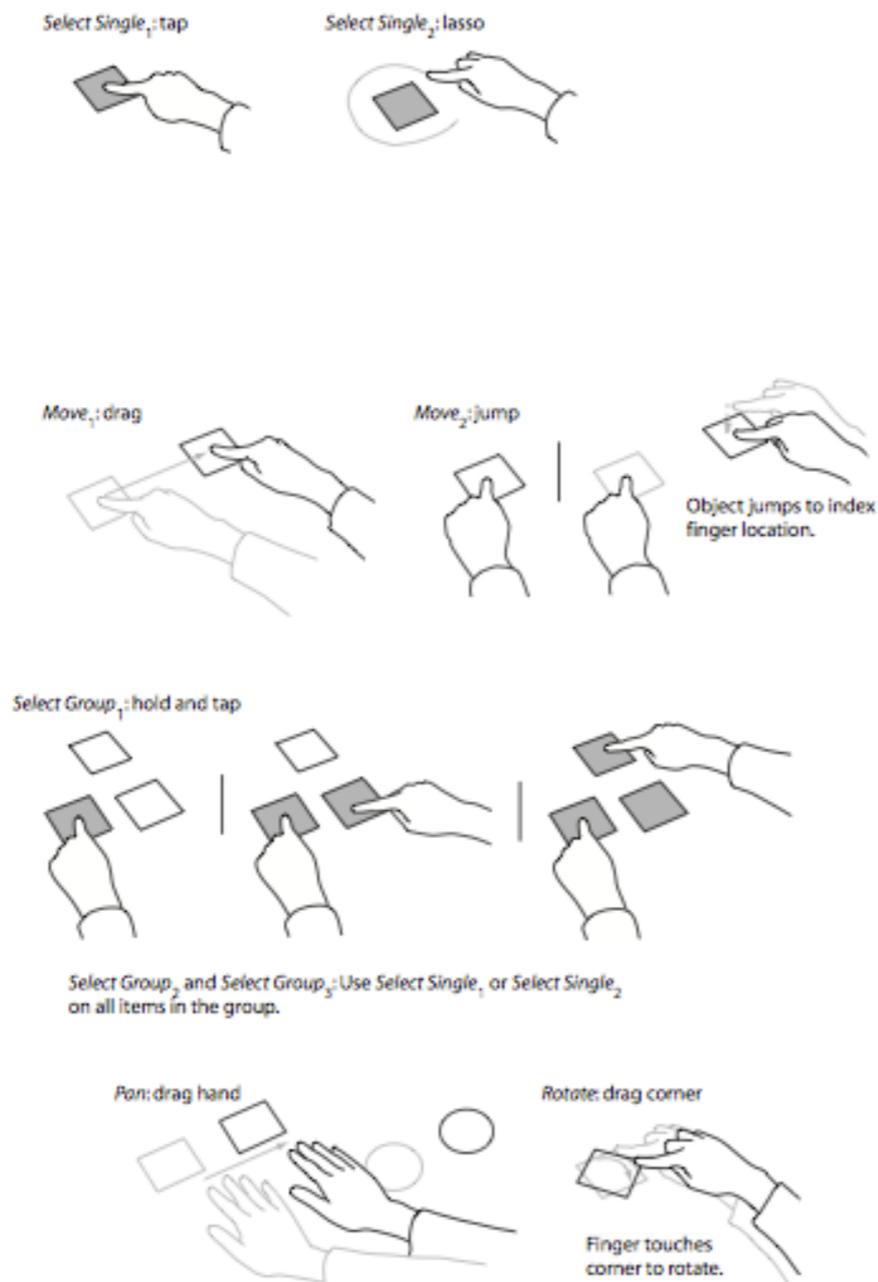


command	number of gestures
accept	1
minimize	3
previous	2
select single	3
help	3
next	2
open	5
move	3
cut	2
rotate	4
shrink	5
delete	5
pan	2
undo	4
select group	3
menu	5
paste	4
reject	5
enlarge	5
zoom in	5
duplicate	4
zoom out	6

Define a mapping

User defined gestures

Capture “natural” mappings



command	number of gestures	% choosing “winner”
accept	1	100%
minimize	3	90.9%
previous	2	90.9%
select single	3	90.9%
help	3	86.4%
next	2	86.4%
open	5	86.4%
move	3	81.8%
cut	2	77.3%
rotate	4	68.2%
shrink	5	68.2%
delete	5	63.6%
pan	2	63.6%
undo	4	63.6%
select group	3	59.1%
menu	5	54.5%
paste	4	54.5%
reject	5	54.5%
enlarge	5	45.5%
zoom in	5	45.0%
duplicate	4	36.4%
zoom out	6	22.7%

Define a mapping

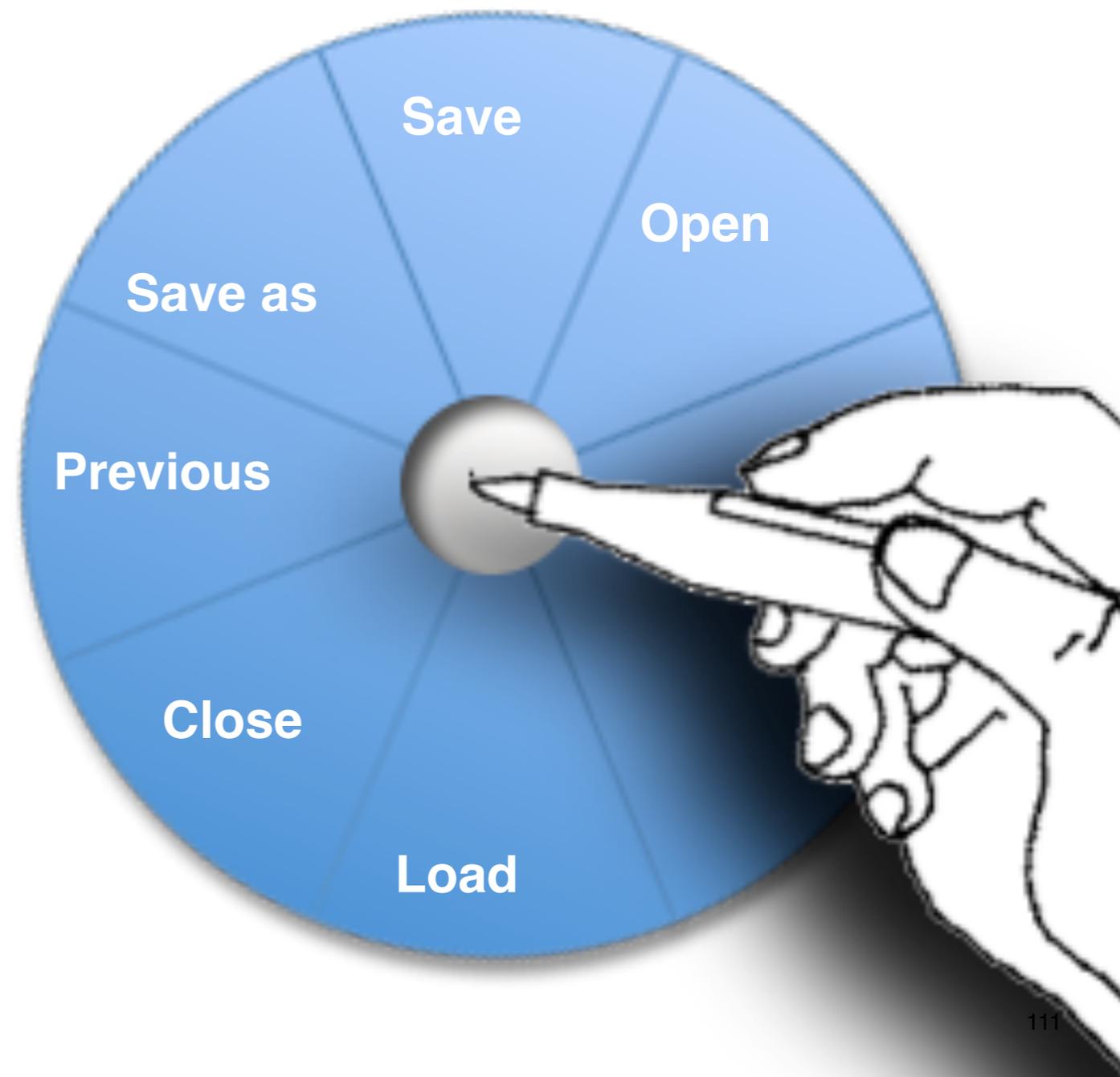
Semantic relationships

Focus on the relation between

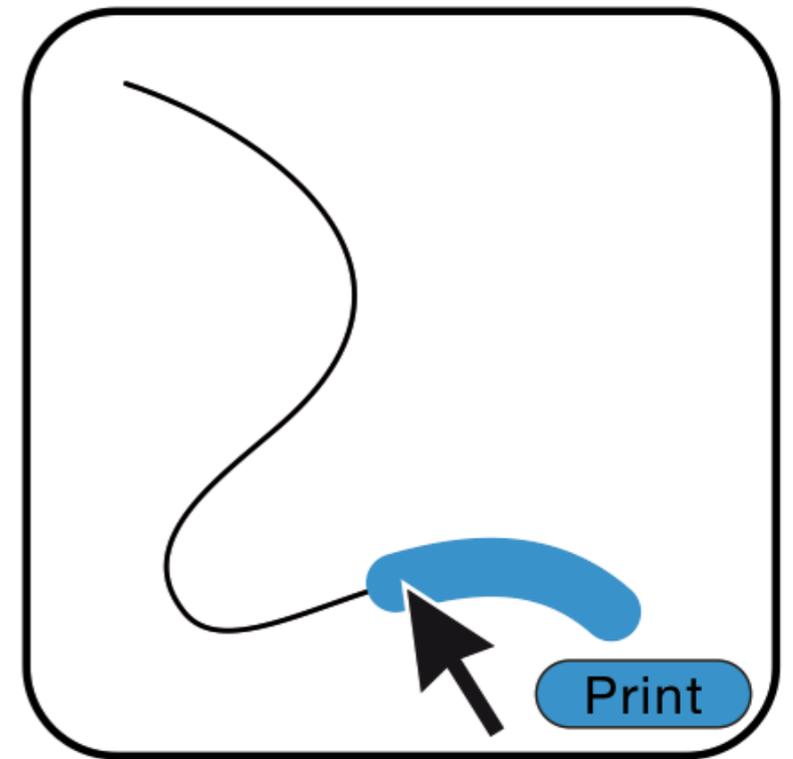
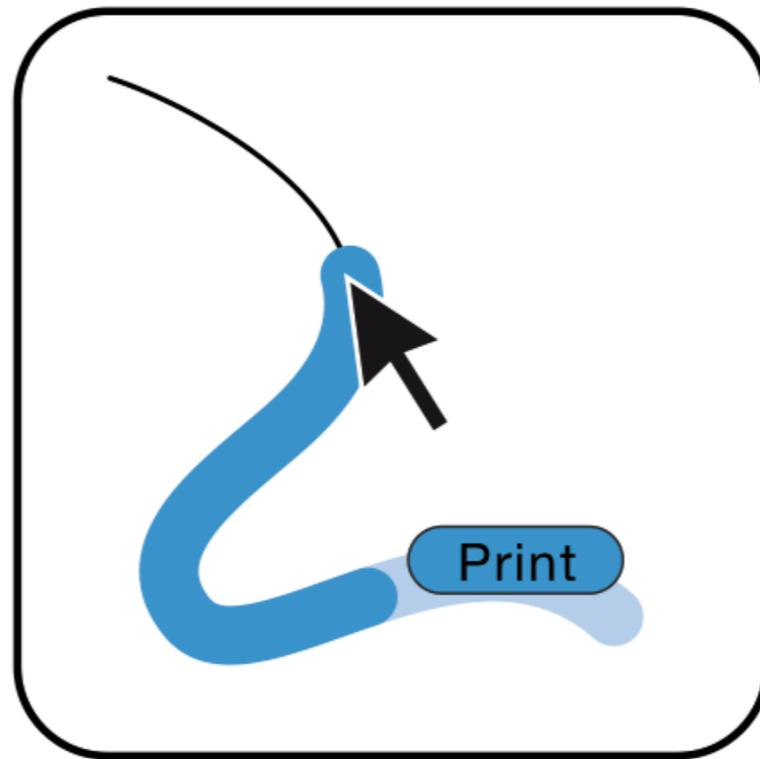
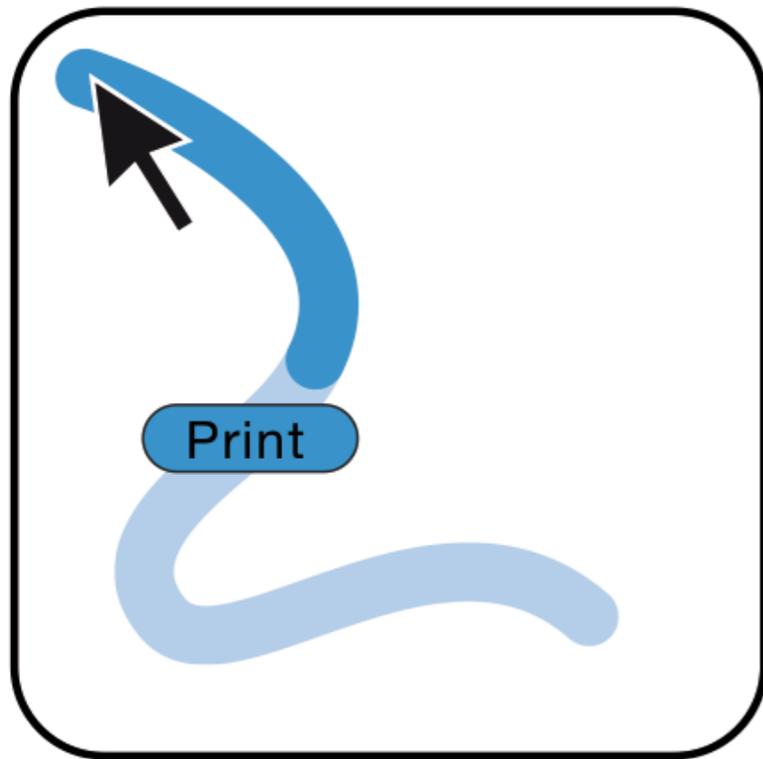
- ▶ the different gestures
- ▶ the different commands

Highlight:

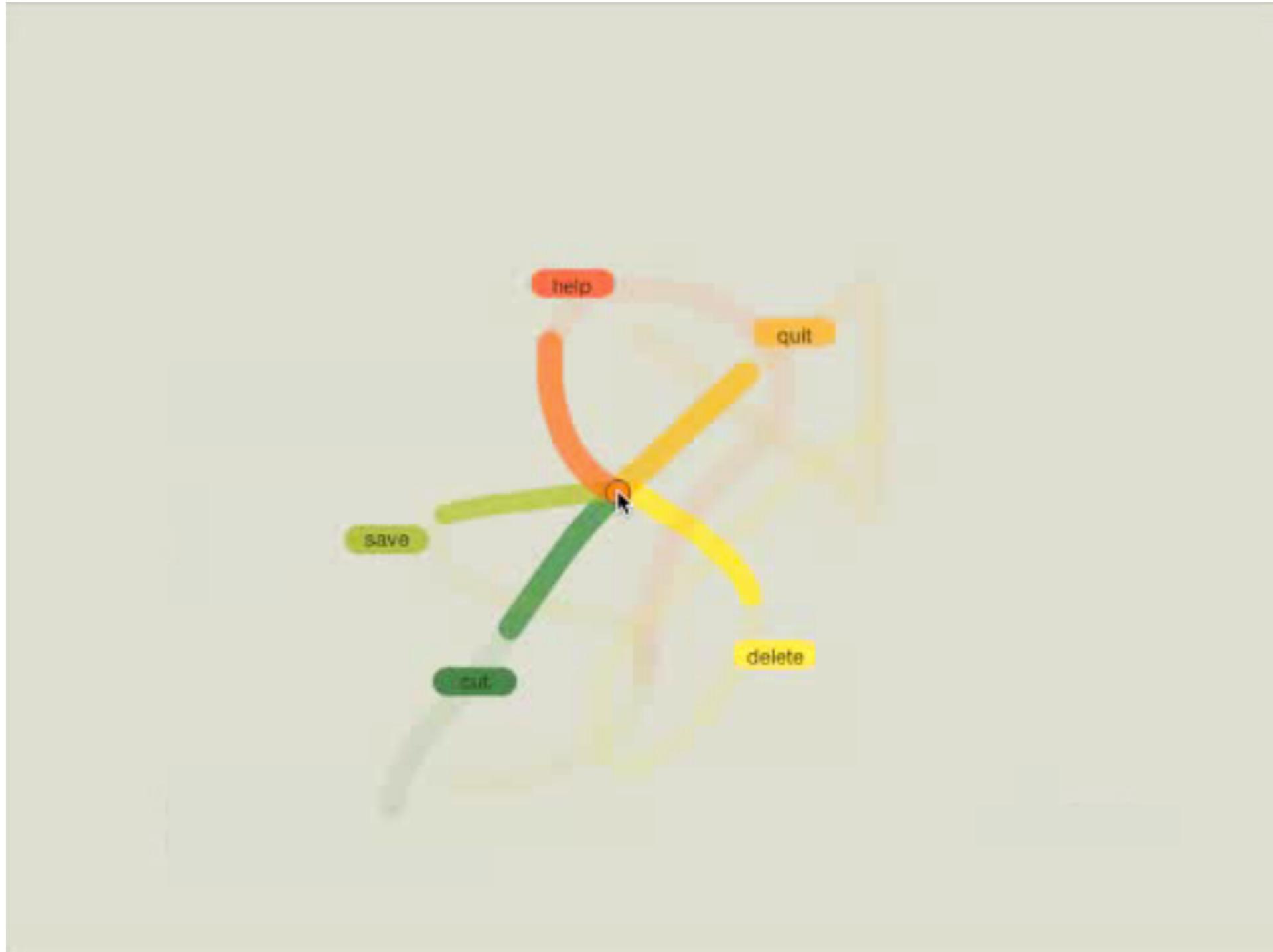
- ▶ Similarity
- ▶ Opposition
- ▶ etc.



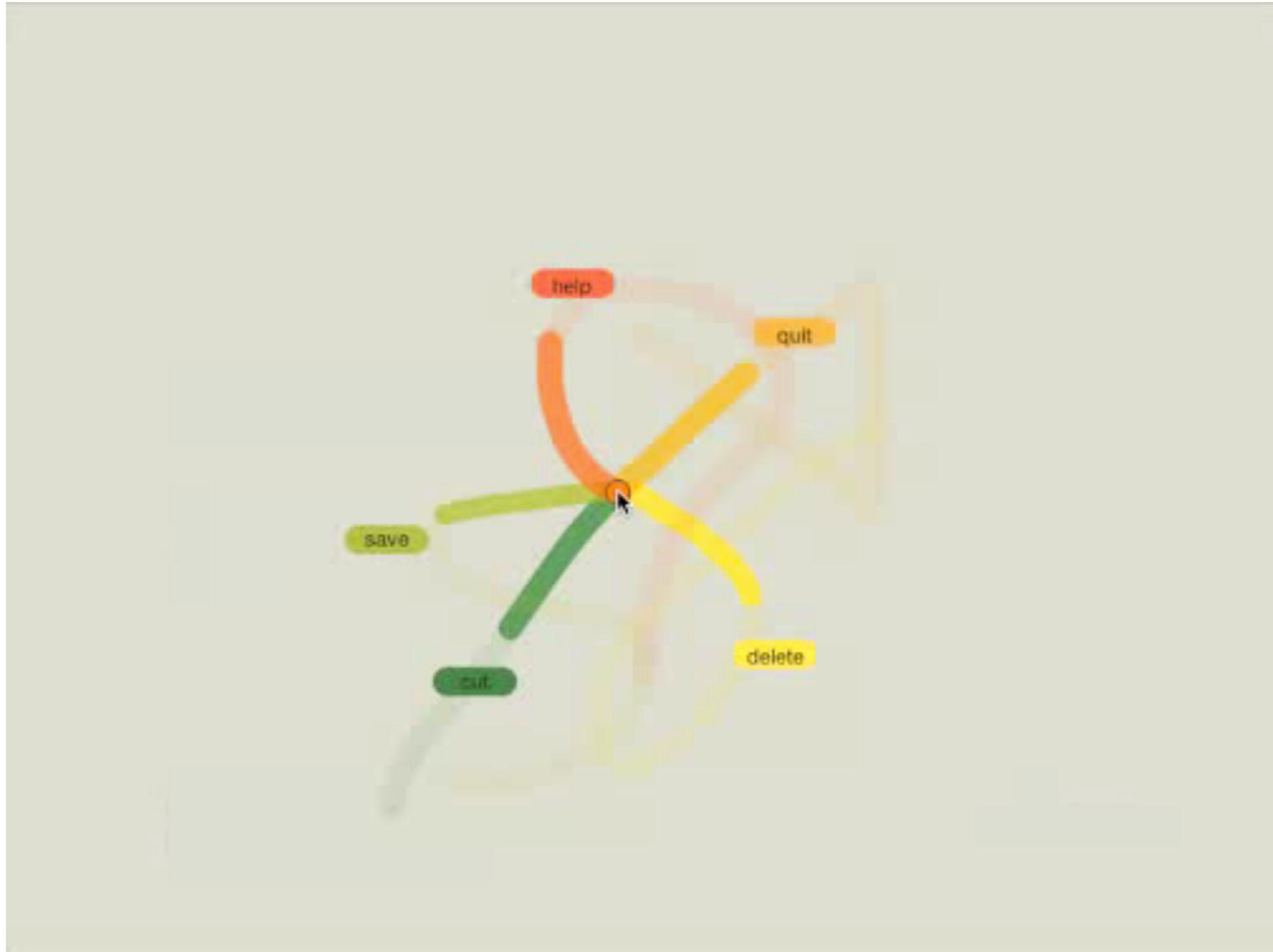
Octopocus [Bau and Mackay]



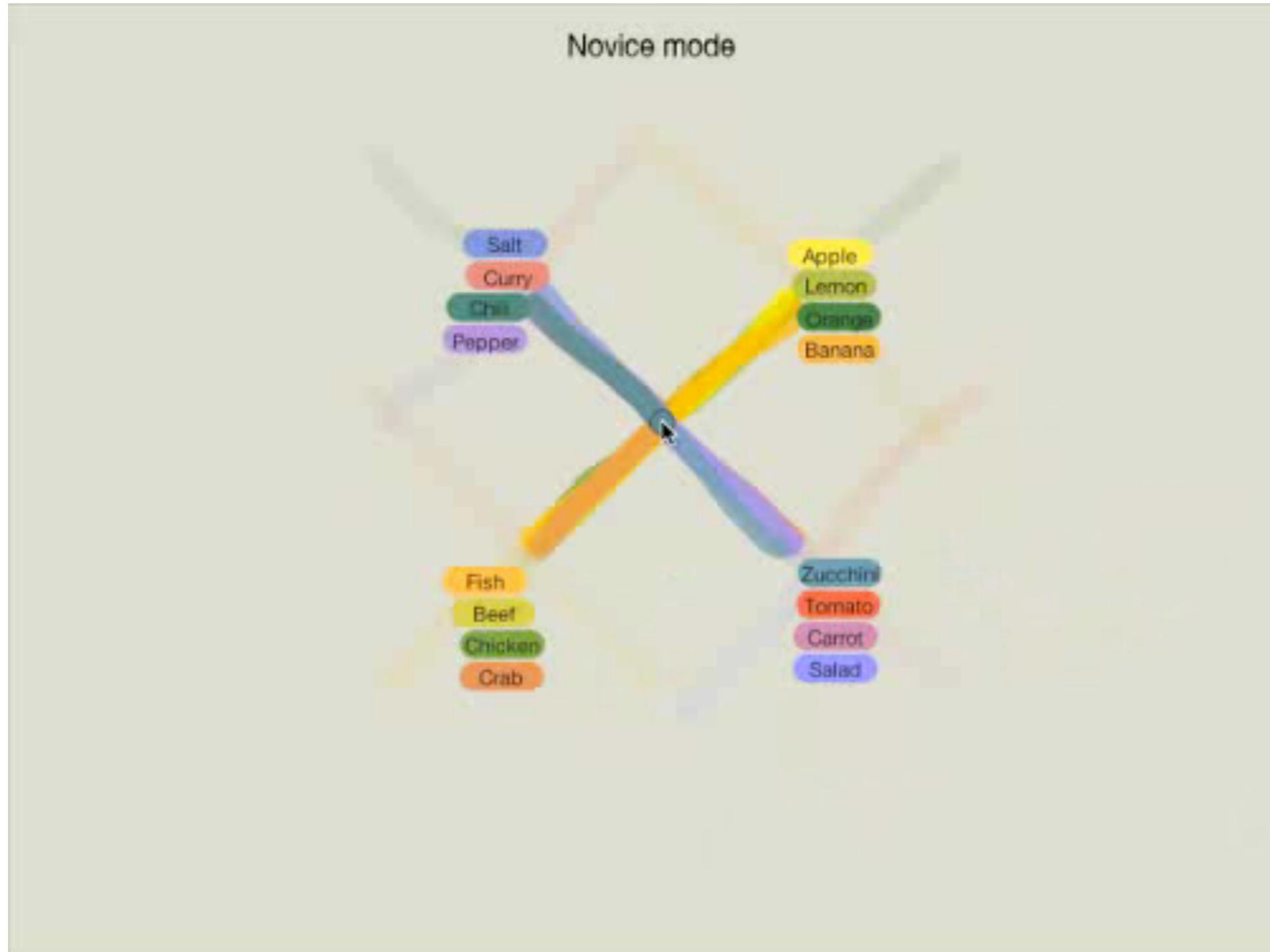
Octopocus [Bau and Mackay]



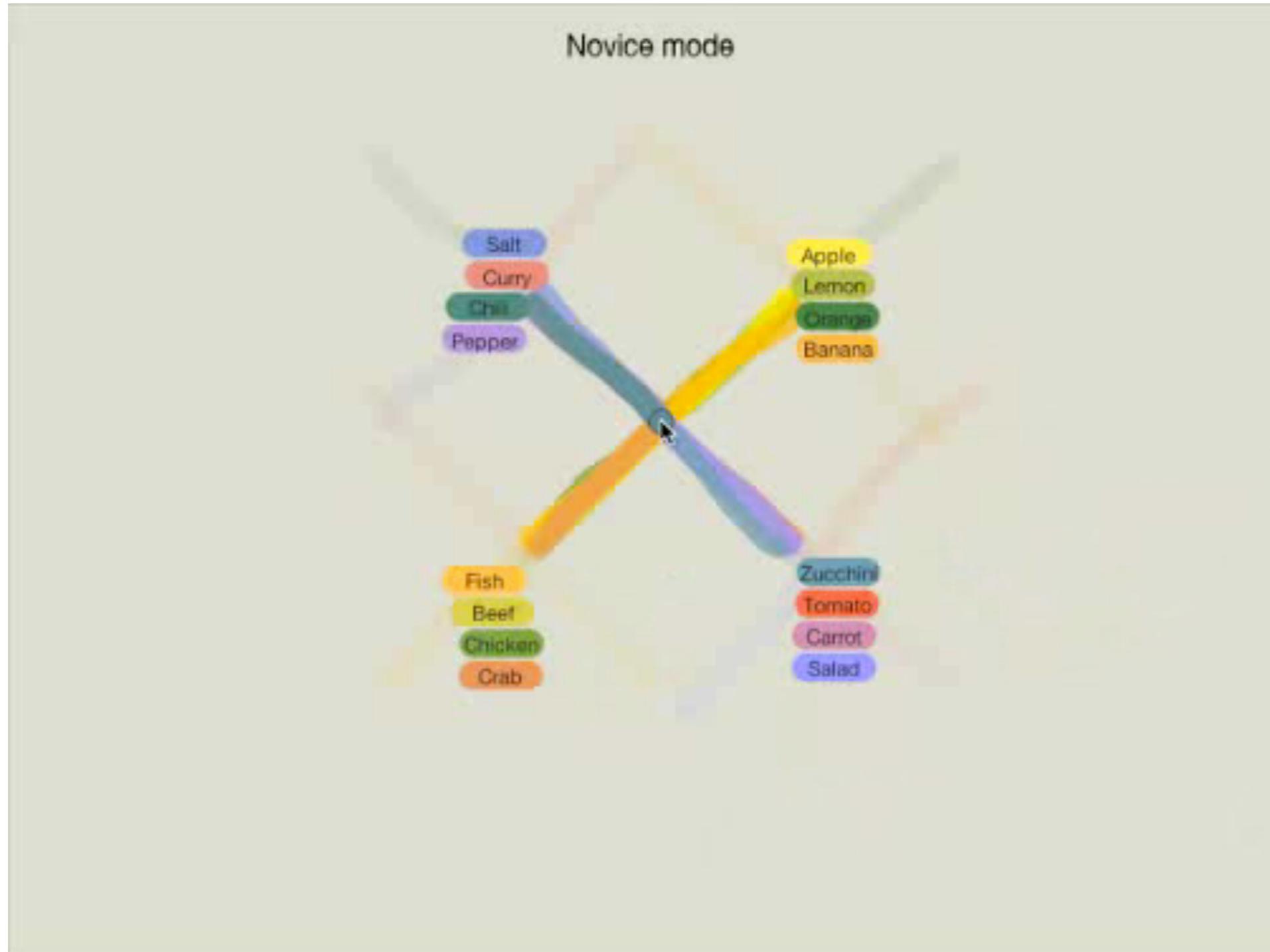
Octopocus [Bau and Mackay]



Octopocus [Bau and Mackay]



Octopocus [Bau and Mackay]

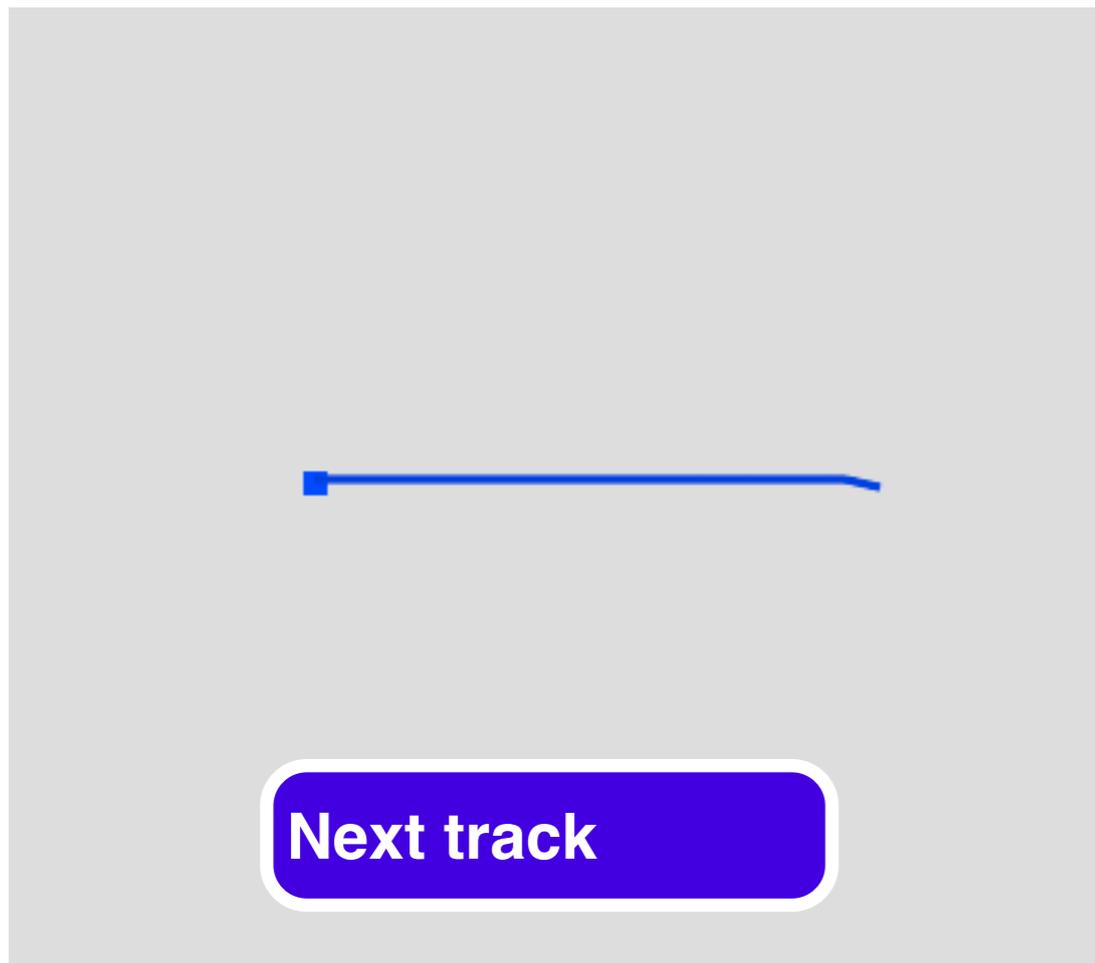


Touch-screen gestures design guidelines

Zhai, S., Kristensson, P. O., Appert, C., Andersen, T. H., & Cao, X. (2012). Foundational Issues in Touch-Screen Stroke Gesture Design-An Integrative Review. *Foundations and Trends in Human-Computer Interaction*, 5(2), 97-205.

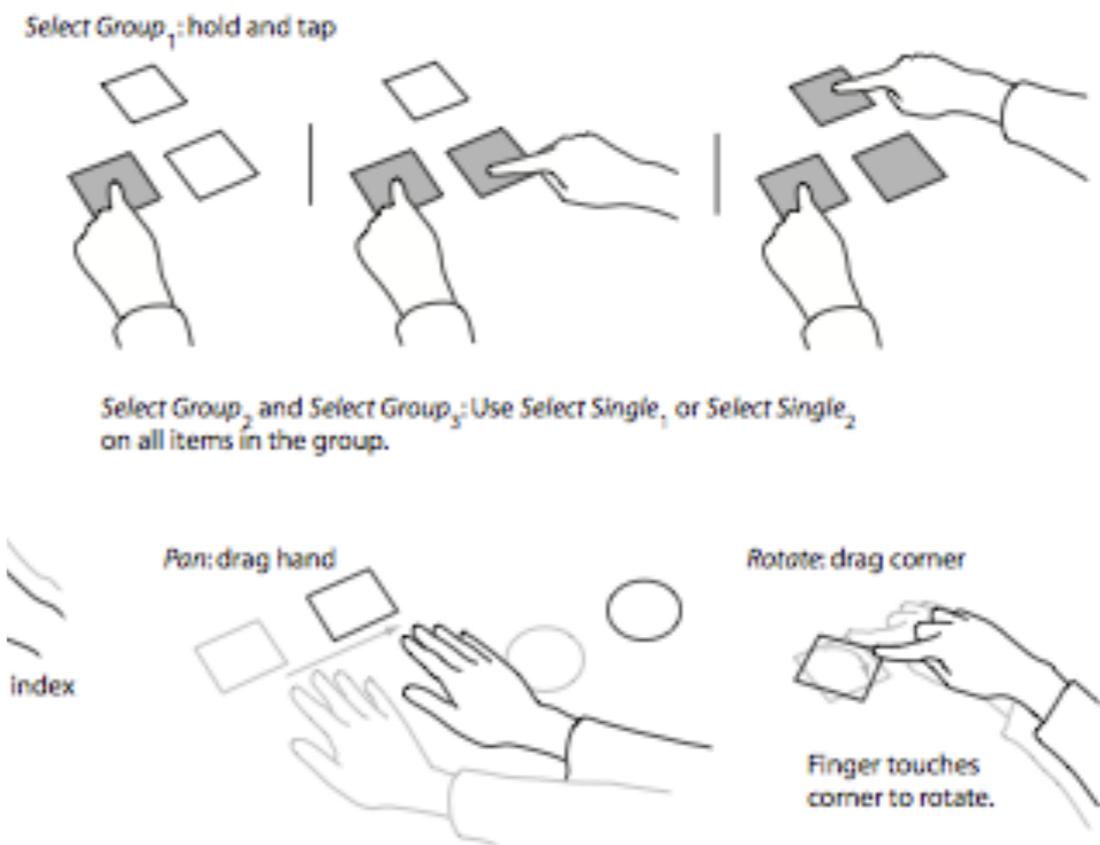
Gesture design guidelines [zhai et al. 2012]

Making Gestures Analogous to Physics or Convention



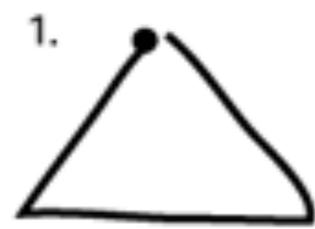
Gesture design guidelines [zhai et al. 2012]

Make gestures accessible to novices



Gesture design guidelines [zhai et al. 2012]

Making gestures as simple as possible



triangle



"X"



rectangle



circle



check



caret



zig-zag

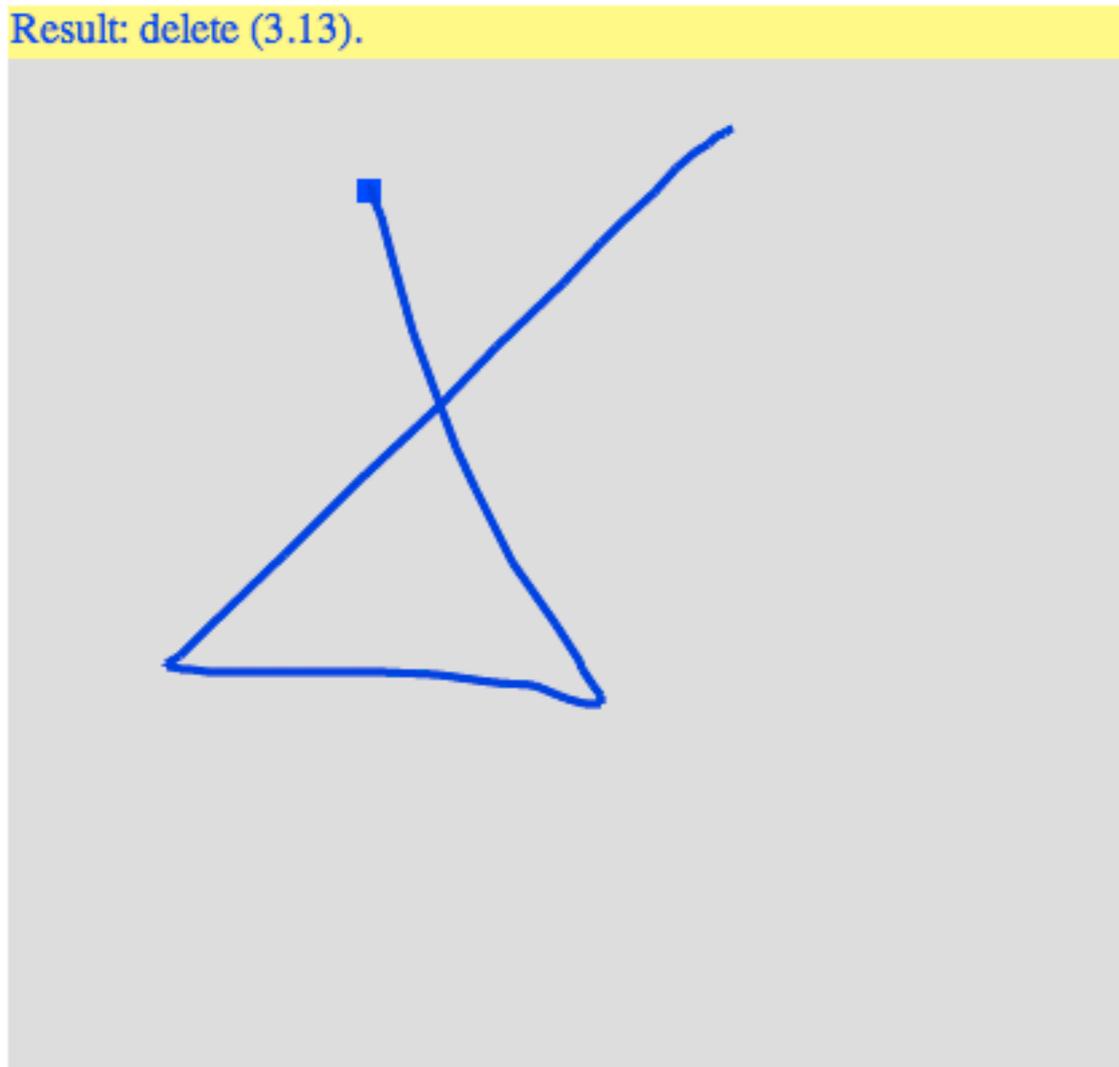


arrow

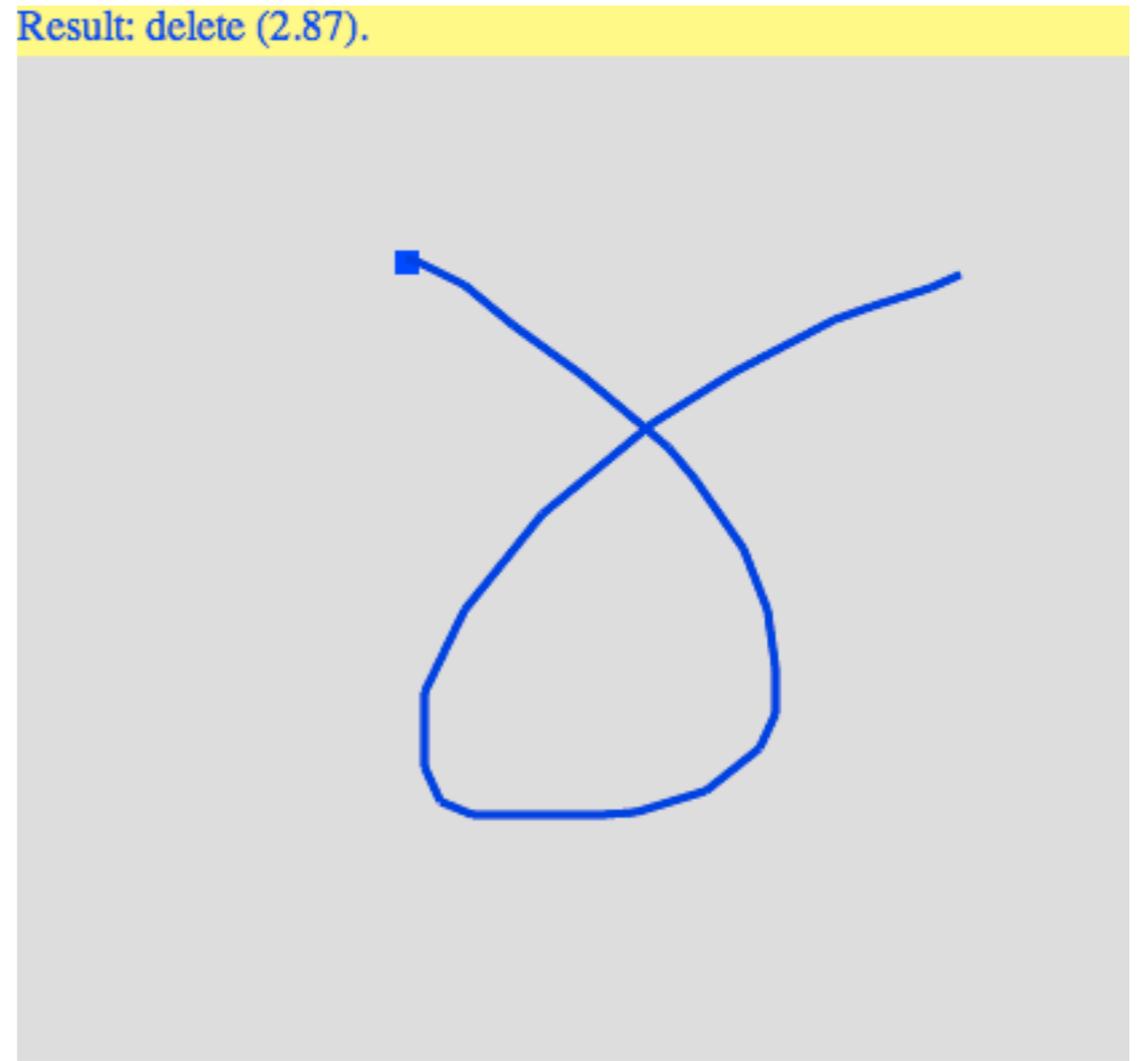
Gesture design guidelines [zhai et al. 2012]

Making Gestures Distinct

Result: delete (3.13).



Result: delete (2.87).



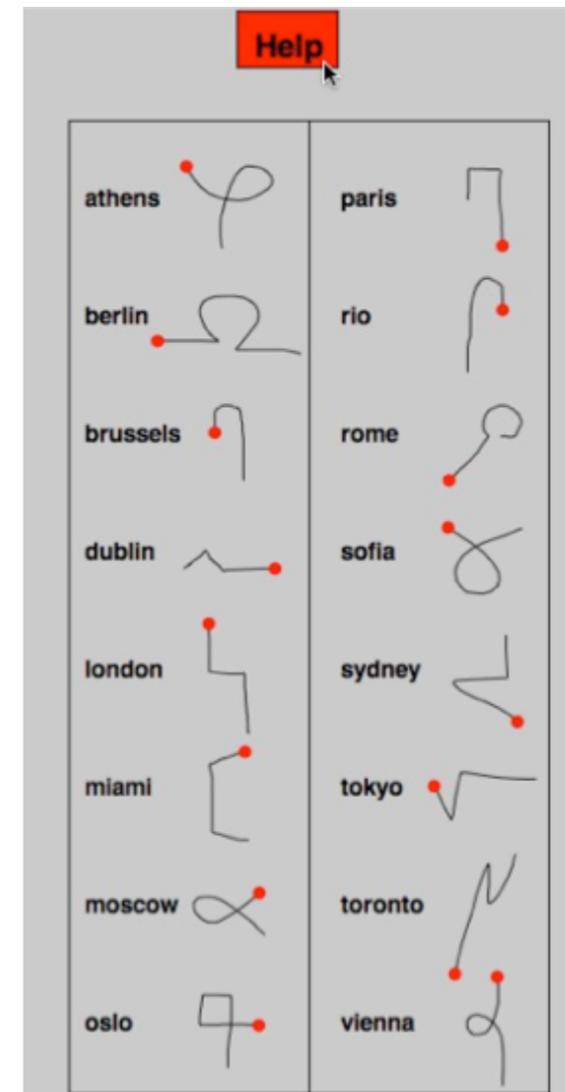
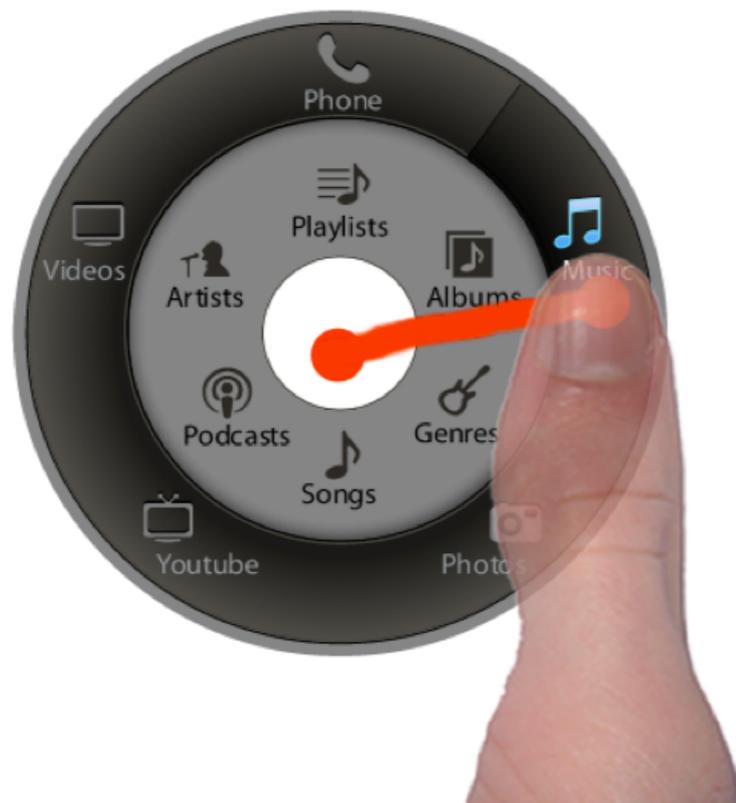
Gesture design guidelines [zhai et al. 2012]

Making gestures systematic



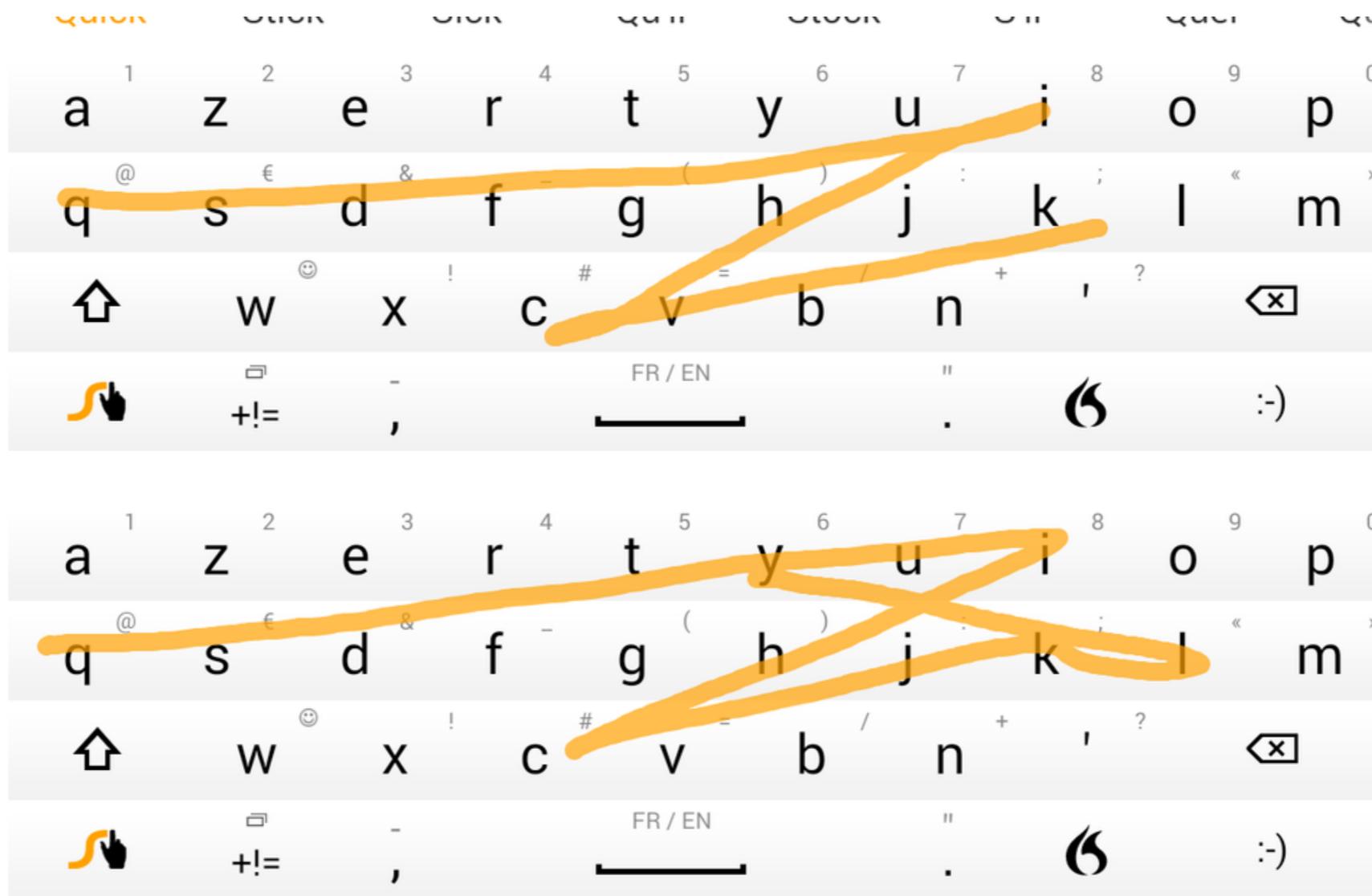
Gesture design guidelines [zhai et al. 2012]

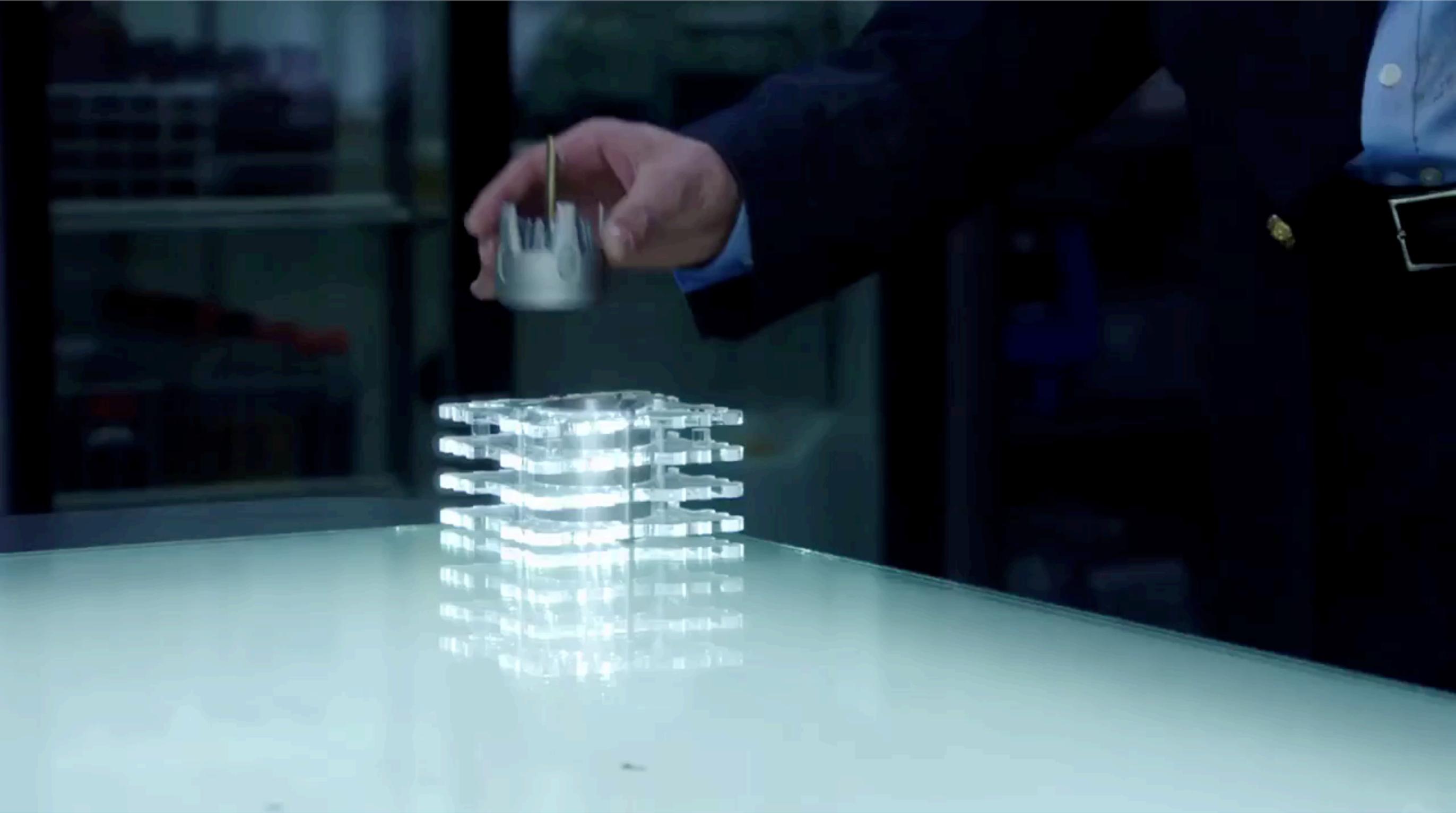
Making gestures self-revealing

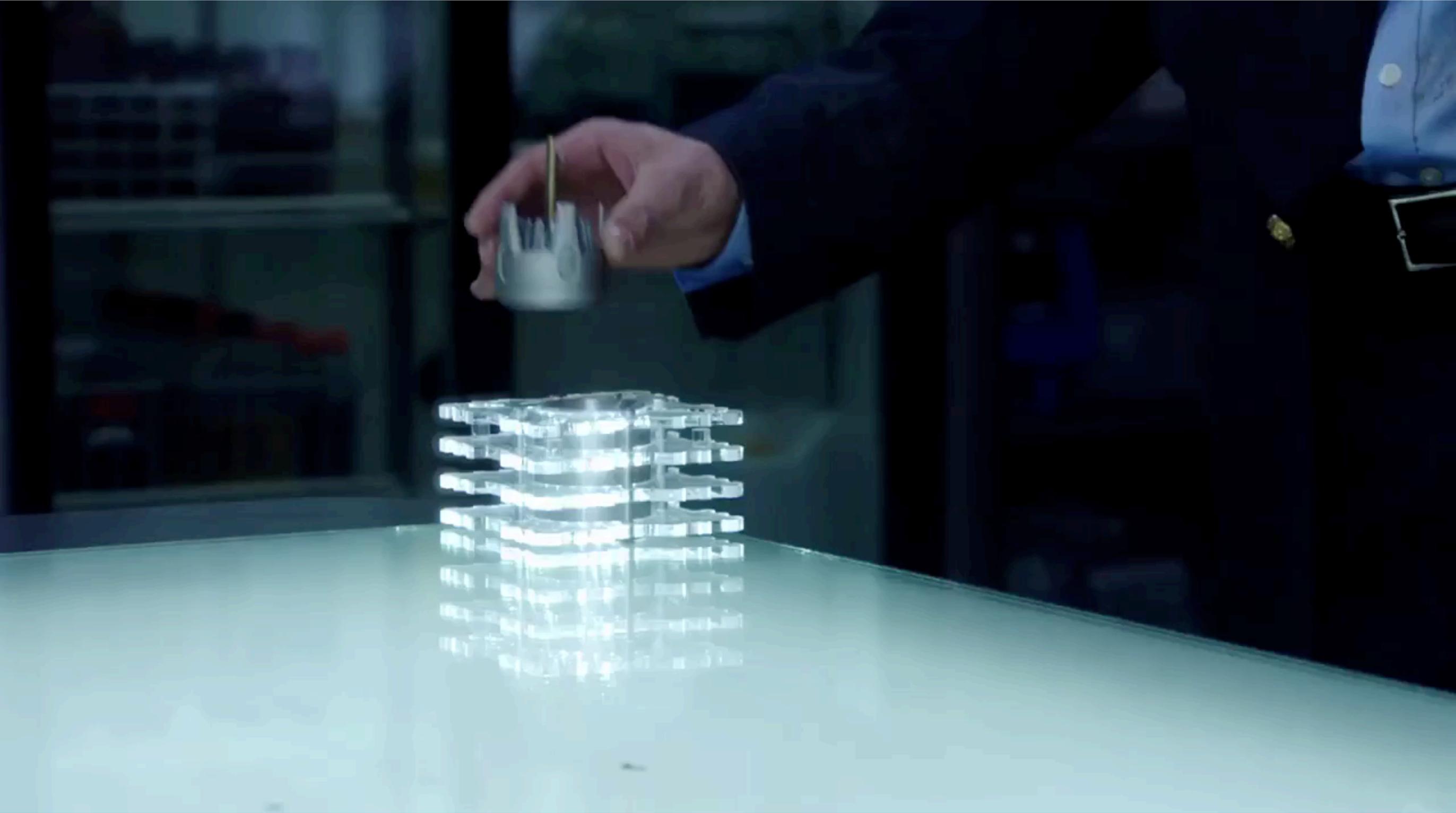


Gesture design guidelines [zhai et al. 2012]

Supporting the right level of chunking







Techniques de reconnaissance

Classifieurs statistiques

Modèles de Markov cachés

Réseaux de neurones

Méthodes ad-hoc

3 techniques fréquemment utilisées:

- Rubine
- 1\$ recognizer
- **Dynamic Time Warping (DTW)**

Techniques de reconnaissance

\$1 recognizer

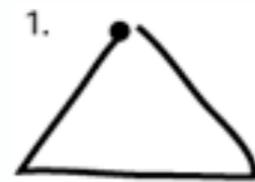
Simple à implémenter

Taux de reconnaissance comparables à Rubine et DTW

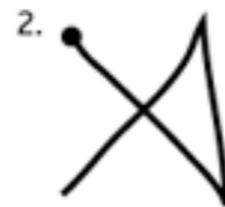
1 seul exemple suffit

*Jacob O. Wobbrock, Andrew D. Wilson, Yang Li.
Gestures without libraries, toolkits or training: a \$1 recognizer for user interface prototypes
UIST '07, 159-168.*

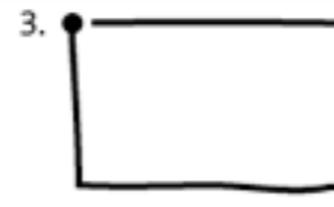
\$1 recognizer



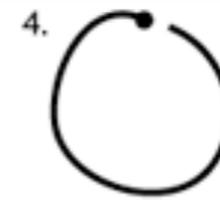
triangle



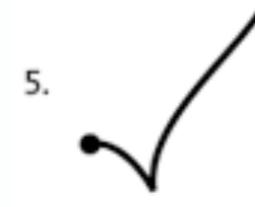
"x"



rectangle



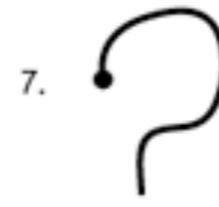
circle



check



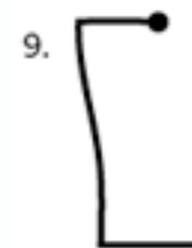
caret



question



arrow



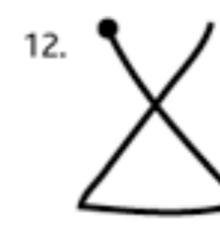
left square bracket



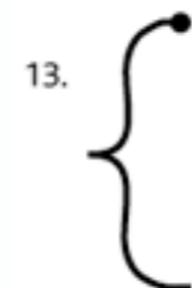
right square bracket



"v"



delete



left curly brace



right curly brace



star



pigtail

Algorithme

A. L'utilisateur réalise un geste

- ▶ Le geste est représenté par une liste ordonnée de points

B. Ce geste est comparé à un ensemble de gestes de référence

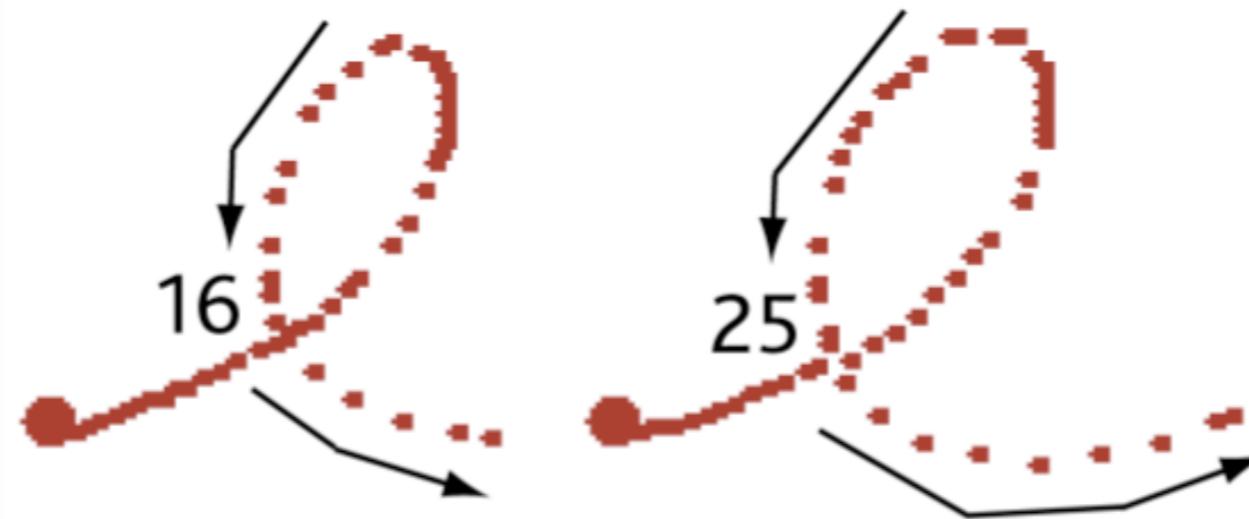
- Les références sont appelées « templates »
- On mesure la distance euclidienne

C. Le geste reconnu est celui pour lequel cette distance est minimale

Problèmes posés

Le nombre de points d'un geste dépend de :

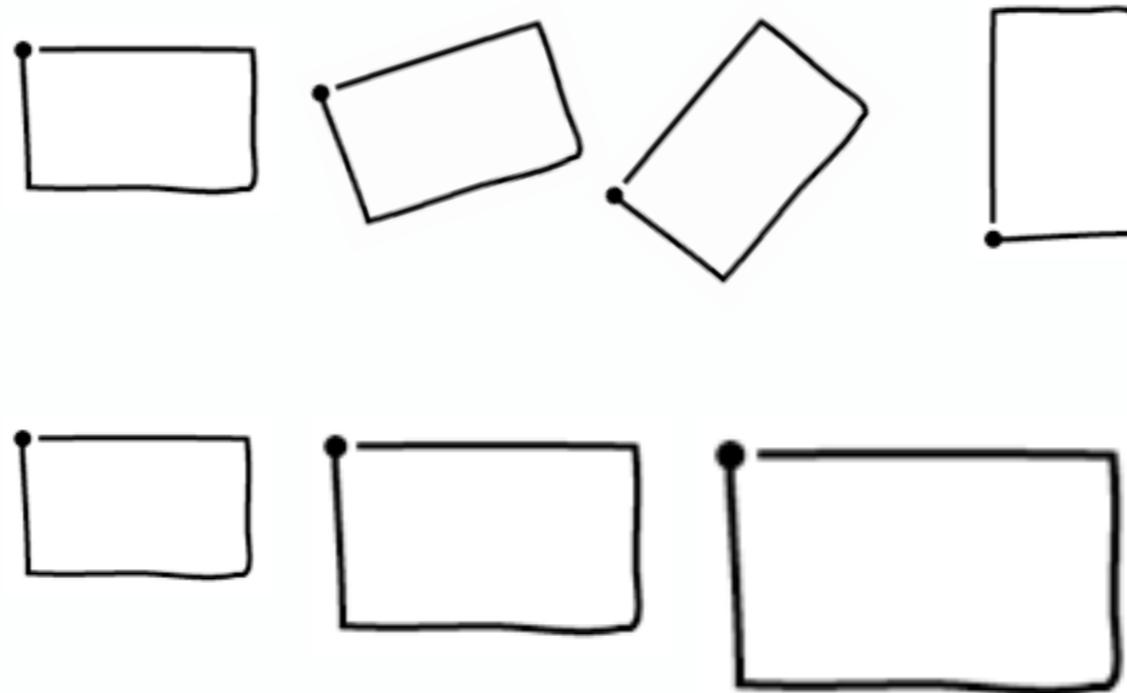
- La vitesse d'exécution
- La fréquence d'échantillonnage du périphérique
- ...



Problèmes posés

Un geste peut être réalisé à différentes positions sur l'interface.

Suivant différentes orientations et différentes échelles.



4 étapes

A. Ré-échantillonner le geste

→ Invariant à la fréquence d'acquisition

→ Invariant à la vitesse d'exécution

B. Ré-orientation du geste

→ Invariant à l'orientation

C. Mise à l'échelle et translation

→ Invariant à l'échelle

→ Invariant à la position

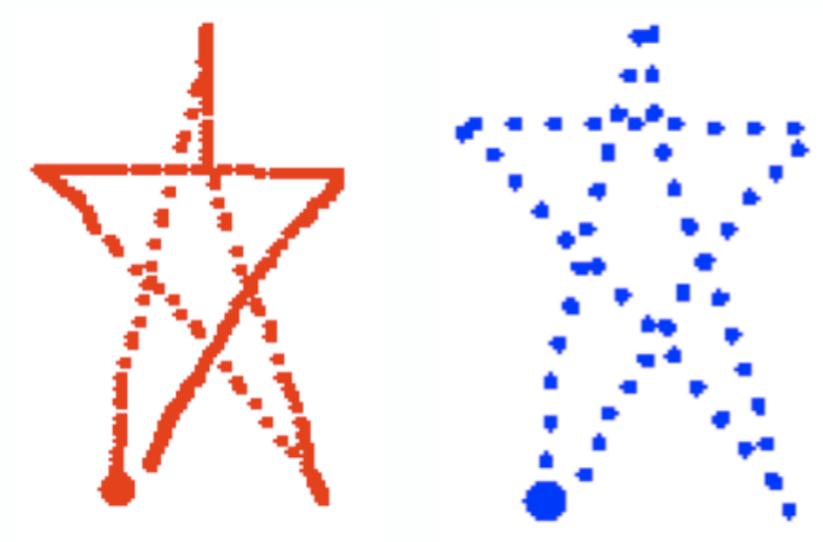
D. Reconnaissance du geste

1ère étape : Ré-échantillonnage

Le geste est défini par M points ordonnés.

On veut N points ordonnés équidistants les uns des autres.

$N = 64$



1ère étape : Ré-échantillonnage

A. Calcul de la distance l entre 2 points :

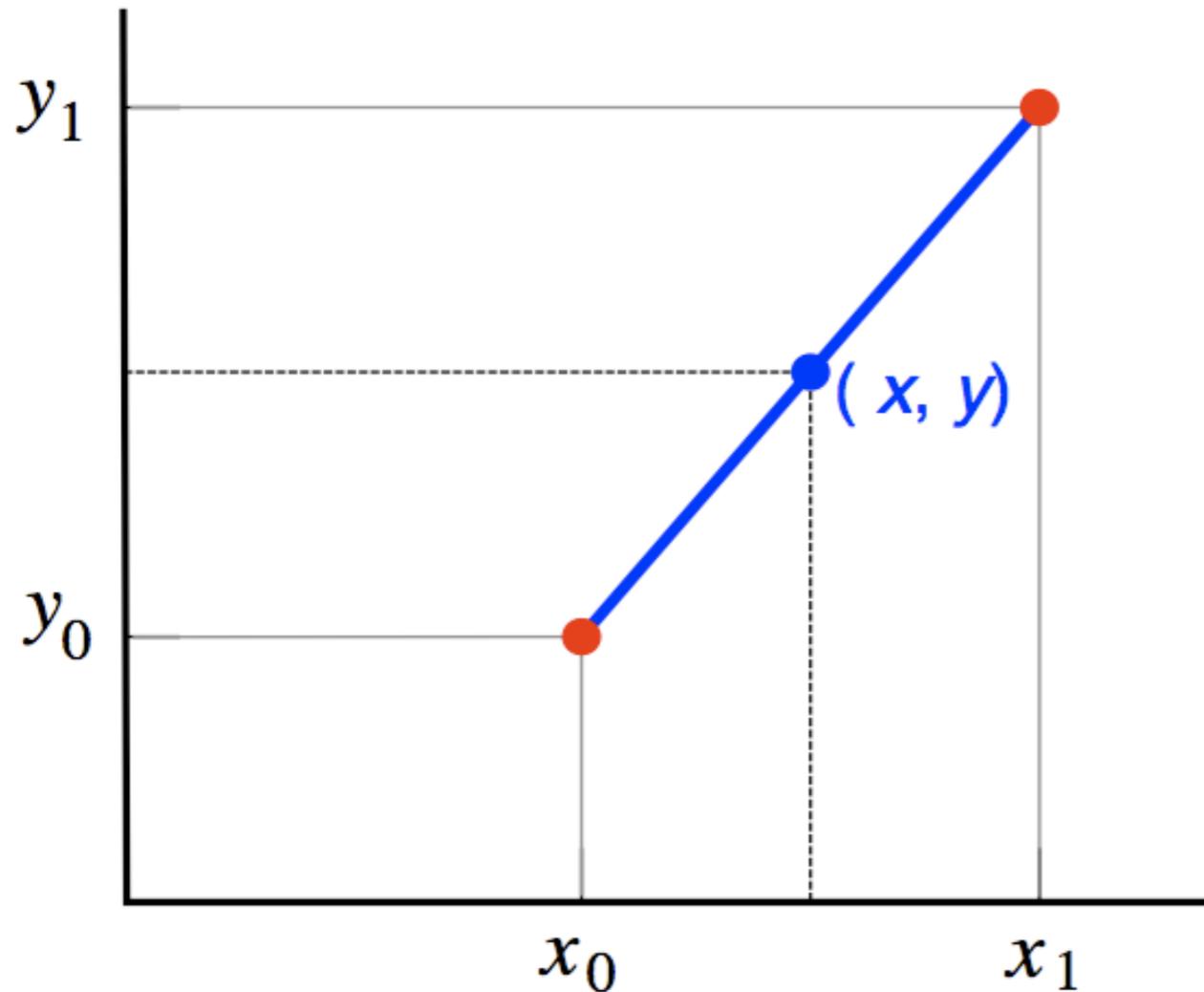
- ▶ Calcul de la longueur totale du geste.
- ▶ $l = \text{longueur} / (N-1)$

B. Interpolation linéaire sur les points du geste d'origine.

- ➔ Permet de calculer la distance en prenant les points 2 à 2.

1ère étape : Ré-échantillonnage

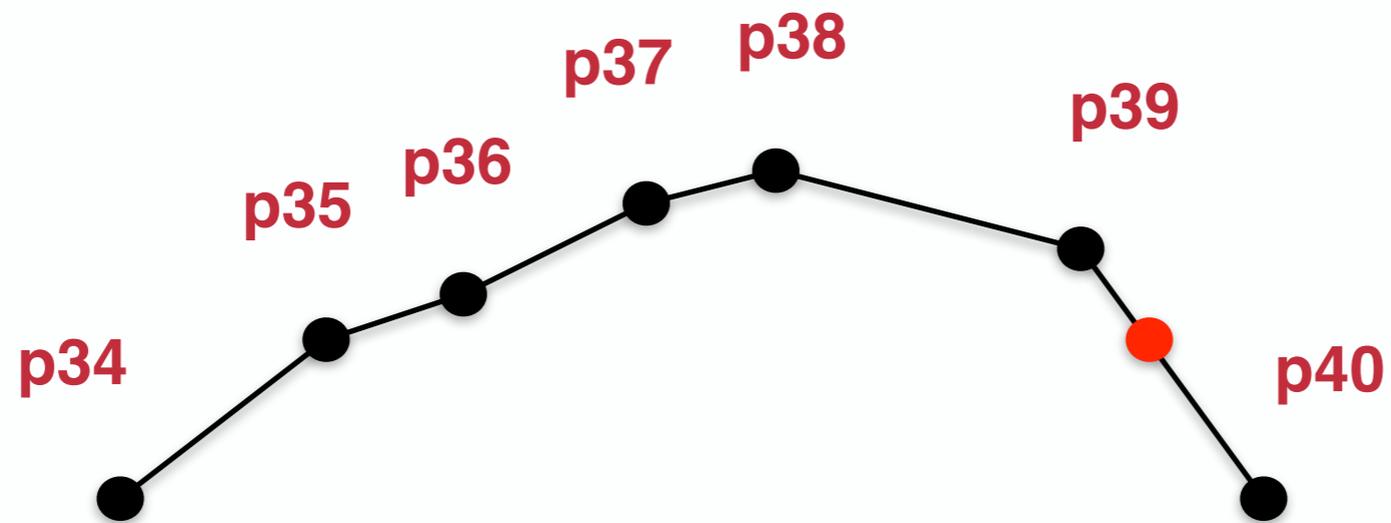
Interpolation linéaire



$$\frac{y - y_0}{x - x_0} = \frac{y_1 - y_0}{x_1 - x_0}$$

$$y = y_0 + (x - x_0) \frac{y_1 - y_0}{x_1 - x_0}$$

1ère étape : Ré-échantillonnage



$$\sum_{i=35}^{40} distance(p_{i-1}, p_i) > I$$

1ère étape : Ré-échantillonnage

Step 1. Resample a *points* path into *n* evenly spaced points.

RESAMPLE(*points*, *n*)

```
1   $I \leftarrow \text{PATH-LENGTH}(\textit{points}) / (n - 1)$ 
2   $D \leftarrow 0$ 
3   $\textit{newPoints} \leftarrow \textit{points}_0$ 
4  foreach point  $p_i$  for  $i \geq 1$  in points do
5     $d \leftarrow \text{DISTANCE}(p_{i-1}, p_i)$ 
6    if  $(D + d) \geq I$  then
7       $q_x \leftarrow p_{i-1}_x + ((I - D) / d) \times (p_{i_x} - p_{i-1}_x)$ 
8       $q_y \leftarrow p_{i-1}_y + ((I - D) / d) \times (p_{i_y} - p_{i-1}_y)$ 
9      APPEND(newPoints, q)
10     INSERT(points, i, q) // q will be the next  $p_i$ 
11      $D \leftarrow 0$ 
12   else  $D \leftarrow D + d$ 
13 return newPoints
```

PATH-LENGTH(*A*)

```
1   $d \leftarrow 0$ 
2  for i from 1 to  $|A|$  step 1 do
3     $d \leftarrow d + \text{DISTANCE}(A_{i-1}, A_i)$ 
4  return d
```

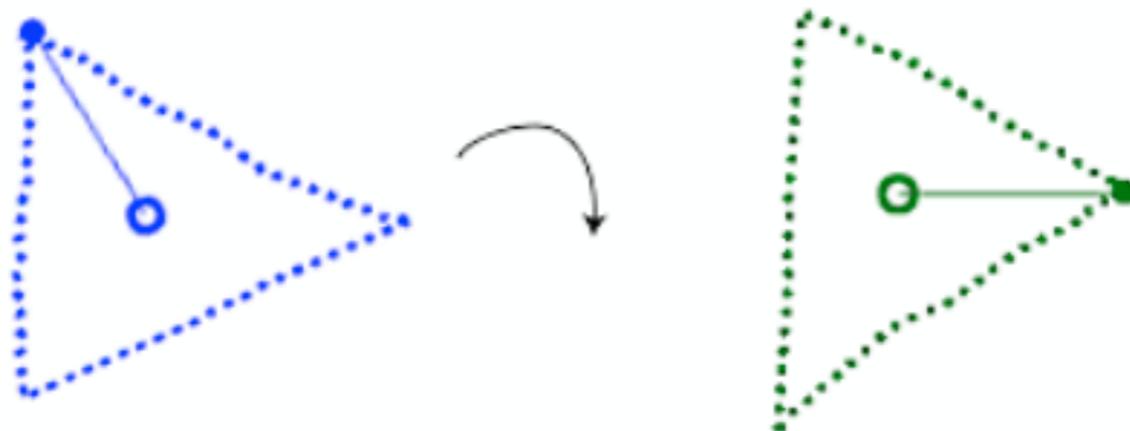
2e étape : Rotation « indicative »

A. Calcul du centre du geste (centroïde)

B. Calcul de l'angle entre :

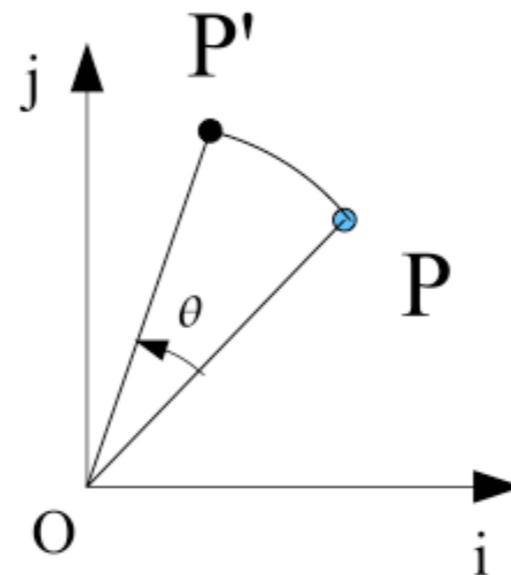
- Le centroïde,
- Le premier point
- L'horizontale

C. Rotation des points en utilisant cet angle



2e étape : Rotation « indicative »

Rotation d'un point



$$\begin{cases} x' &= x \cos(\theta) - y \sin(\theta) \\ y' &= x \sin(\theta) + y \cos \theta \end{cases}$$

Comment retrouver ? Soit α l'angle (i, OP) et $r = \|OP'\| = \|OP\|$. Alors

$$\begin{cases} x' &= r \cos(\alpha + \theta) \\ y' &= r \sin(\alpha + \theta) \end{cases}$$

$$\begin{cases} x' &= r \cos(\alpha) \cos(\theta) - r \sin(\alpha) \sin(\theta) \\ y' &= r \cos(\alpha) \sin(\theta) + r \sin(\alpha) \cos(\theta) \end{cases}$$

or $x = r \cos(\alpha)$ et $y = r \sin(\alpha)$

2e étape : Rotation « indicative »

Step 2. Rotate *points* so that their indicative angle is at 0° .

ROTATE-TO-ZERO(*points*)

- 1 $c \leftarrow \text{CENTROID}(\textit{points})$ // computes (\bar{x}, \bar{y})
- 2 $\theta \leftarrow \text{ATAN}(c_y - \textit{points}_{0_y}, c_x - \textit{points}_{0_x})$ // for $-\pi \leq \theta \leq \pi$
- 3 $\textit{newPoints} \leftarrow \text{ROTATE-BY}(\textit{points}, -\theta)$
- 4 **return** *newPoints*

ROTATE-BY(*points*, θ)

- 1 $c \leftarrow \text{CENTROID}(\textit{points})$
- 2 **foreach** point *p* in *points* **do**
- 3 $q_x \leftarrow (p_x - c_x) \cos \theta - (p_y - c_y) \sin \theta + c_x$
- 4 $q_y \leftarrow (p_x - c_x) \sin \theta + (p_y - c_y) \cos \theta + c_y$
- 5 APPEND(*newPoints*, *q*)
- 6 **return** *newPoints*

3e étape : mise à l'échelle et translation

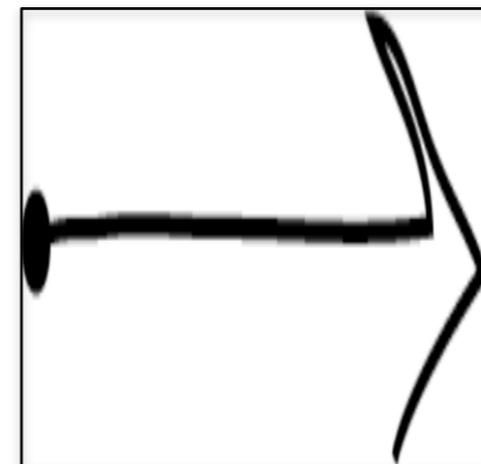
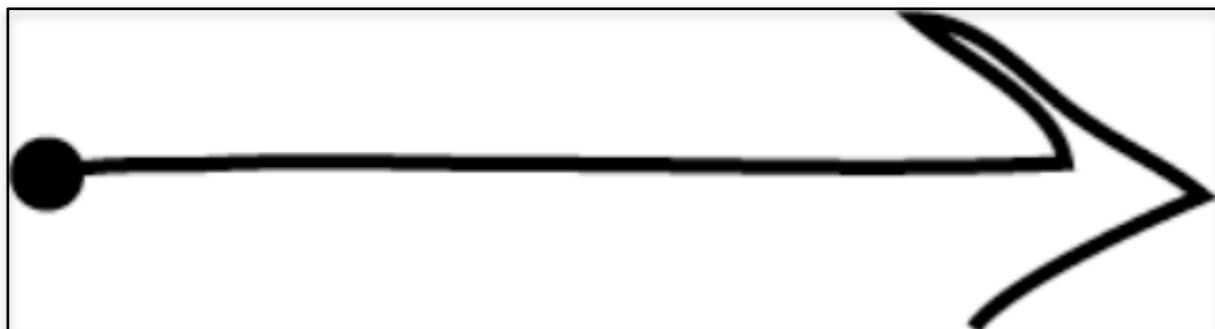
Mise à l'échelle non uniforme: on ramène le geste à un carré de référence

A. Calcul de la bounding box

- ▶ Calcul de minx , maxx , miny , maxy

B. Mise à l'échelle

C. Translation à l'origine



3e étape : mise à l'échelle et translation

Step 3. Scale *points* so that the resulting bounding box will be of $size^2$ dimension; then translate *points* to the origin. BOUNDING-BOX returns a rectangle according to (min_x, min_y) , (max_x, max_y) . For gestures serving as templates, Steps 1-3 should be carried out once on the raw input points. For candidates, Steps 1-4 should be used just after the candidate is articulated.

SCALE-TO-SQUARE(*points*, *size*)

```
1   $B \leftarrow \text{BOUNDING-BOX}(\textit{points})$ 
2  foreach point  $p$  in points do
3     $q_x \leftarrow p_x \times (\textit{size} / B_{\textit{width}})$ 
4     $q_y \leftarrow p_y \times (\textit{size} / B_{\textit{height}})$ 
5    APPEND(newPoints,  $q$ )
6  return newPoints
```

TRANSLATE-TO-ORIGIN(*points*)

```
1   $c \leftarrow \text{CENTROID}(\textit{points})$ 
2  foreach point  $p$  in points do
3     $q_x \leftarrow p_x - c_x$ 
4     $q_y \leftarrow p_y - c_y$ 
5    APPEND(newPoints,  $q$ )
6  return newPoints
```

4e étape : reconnaissance

Step 4. Match *points* against a set of *templates*. The *size* variable on line 7 of RECOGNIZE refers to the *size* passed to SCALE-TO-SQUARE in Step 3. The symbol φ equals $\frac{1}{2}(-1 + \sqrt{5})$. We use $\theta = \pm 45^\circ$ and $\theta_\Delta = 2^\circ$ on line 3 of RECOGNIZE. Due to using RESAMPLE, we can assume that A and B in PATH-DISTANCE contain the same number of points, i.e., $|A|=|B|$.

RECOGNIZE(*points*, *templates*)

```
1   $b \leftarrow +\infty$ 
2  foreach template  $T$  in templates do
3     $d \leftarrow$  DISTANCE-AT-BEST-ANGLE(points,  $T$ ,  $-\theta$ ,  $\theta$ ,  $\theta_\Delta$ )
4    if  $d < b$  then
5       $b \leftarrow d$ 
6       $T' \leftarrow T$ 
7   $score \leftarrow 1 - b / 0.5\sqrt{(size^2 + size^2)}$ 
8  return  $\langle T', score \rangle$ 
```

4e étape : reconnaissance

Un geste candidat C est comparé à chaque templates T_i

- Calcul de la distance moyenne d_i entre les points

$$d_i = \frac{\sum_{k=1}^N \sqrt{(C[k]_x - T_i[k]_x)^2 + (C[k]_y - T_i[k]_y)^2}}{N}$$

Le template avec le d_i plus faible est le résultat

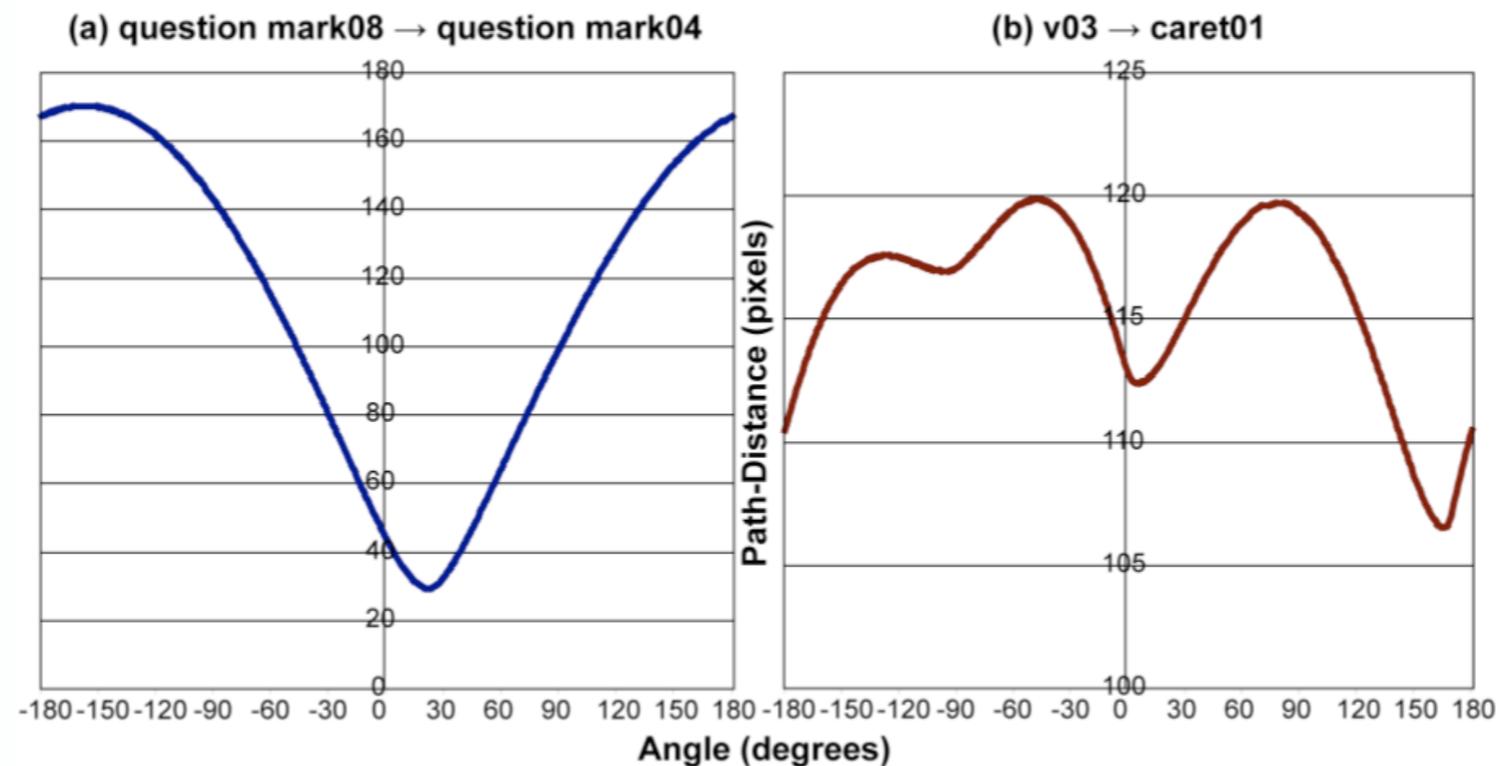
La distance est transformée en score entre 0 et 1

$$score = 1 - \frac{d_i^*}{\frac{1}{2} \sqrt{size^2 + size^2}}$$

4e étape : reconnaissance

L'angle indicatif ne garantit pas que le geste candidat C sera parfaitement aligné avec un template

On cherche à ajuster l'angle de rotation de C pour minimiser la distance entre C et T_i



4e étape : reconnaissance

Méthode du nombre d'or :

- Recherche d'une valeur minimale pour une fonction unimodale

Similaire à la recherche dichotomique

$$a + c = b$$

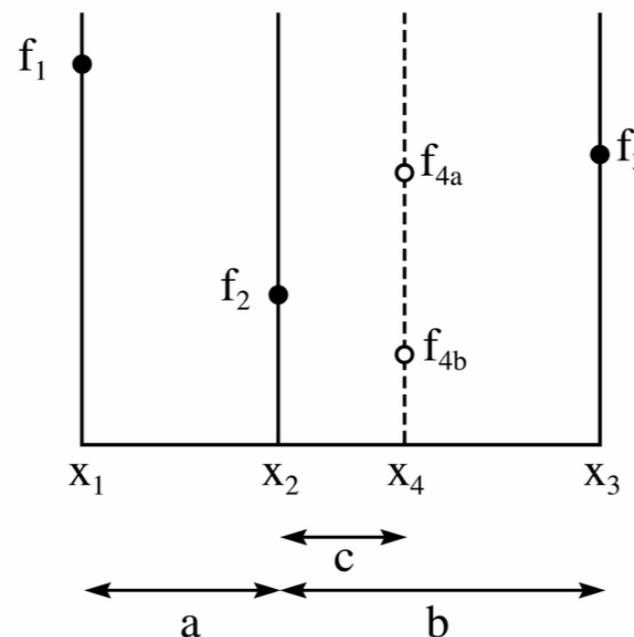
$$c/a = a/b$$

$$\varphi = b/a$$

$$\varphi^2 - \varphi - 1 = 0$$

$$\varphi_1 = (1 + \sqrt{5})/2$$

$$\varphi_2 = (-1 + \sqrt{5})/2$$



$$x_2 = (1 - \varphi)x_1 + \varphi x_4$$

$$x_3 = \varphi x_1 + (1 - \varphi)x_4$$

4e étape : reconnaissance

```
DISTANCE-AT-BEST-ANGLE(points, T,  $\theta_a$ ,  $\theta_b$ ,  $\theta_\Delta$ )
1   $x_1 \leftarrow \varphi\theta_a + (1 - \varphi)\theta_b$ 
2   $f_1 \leftarrow \text{DISTANCE-AT-ANGLE}(\textit{points}, T, x_1)$ 
3   $x_2 \leftarrow (1 - \varphi)\theta_a + \varphi\theta_b$ 
4   $f_2 \leftarrow \text{DISTANCE-AT-ANGLE}(\textit{points}, T, x_2)$ 
5  while  $|\theta_b - \theta_a| > \theta_\Delta$  do
6    if  $f_1 < f_2$  then
7       $\theta_b \leftarrow x_2$ 
8       $x_2 \leftarrow x_1$ 
9       $f_2 \leftarrow f_1$ 
10      $x_1 \leftarrow \varphi\theta_a + (1 - \varphi)\theta_b$ 
11      $f_1 \leftarrow \text{DISTANCE-AT-ANGLE}(\textit{points}, T, x_1)$ 
12   else
13      $\theta_a \leftarrow x_1$ 
14      $x_1 \leftarrow x_2$ 
15      $f_1 \leftarrow f_2$ 
16      $x_2 \leftarrow (1 - \varphi)\theta_a + \varphi\theta_b$ 
17      $f_2 \leftarrow \text{DISTANCE-AT-ANGLE}(\textit{points}, T, x_2)$ 
18 return  $\text{MIN}(f_1, f_2)$ 
```

4e étape : reconnaissance

```
DISTANCE-AT-ANGLE(points, T,  $\theta$ )
1  newPoints  $\leftarrow$  ROTATE-BY(points,  $\theta$ )
2  d  $\leftarrow$  PATH-DISTANCE(newPoints, Tpoints)
3  return d

PATH-DISTANCE(A, B)
1  d  $\leftarrow$  0
2  for i from 0 to |A| step 1 do
3    d  $\leftarrow$  d + DISTANCE(Ai, Bi)
4  return d / |A|
```

Limitations

Pas possible de distinguer un carré d'un rectangle

Pas possible de distinguer une ellipse d'un cercle

Pas possible de distinguer une flèche vers le bas/haut

Pas possible de reconnaître des gestes « 1D »

Classifieur statistique

Rubine

Reconnaissance de gestes à un seul tracé (unistroke)

Traitement statistique de caractéristiques

*Dean Rubine
Specifying gestures by example
SIGGRAPH '91, 329-337*

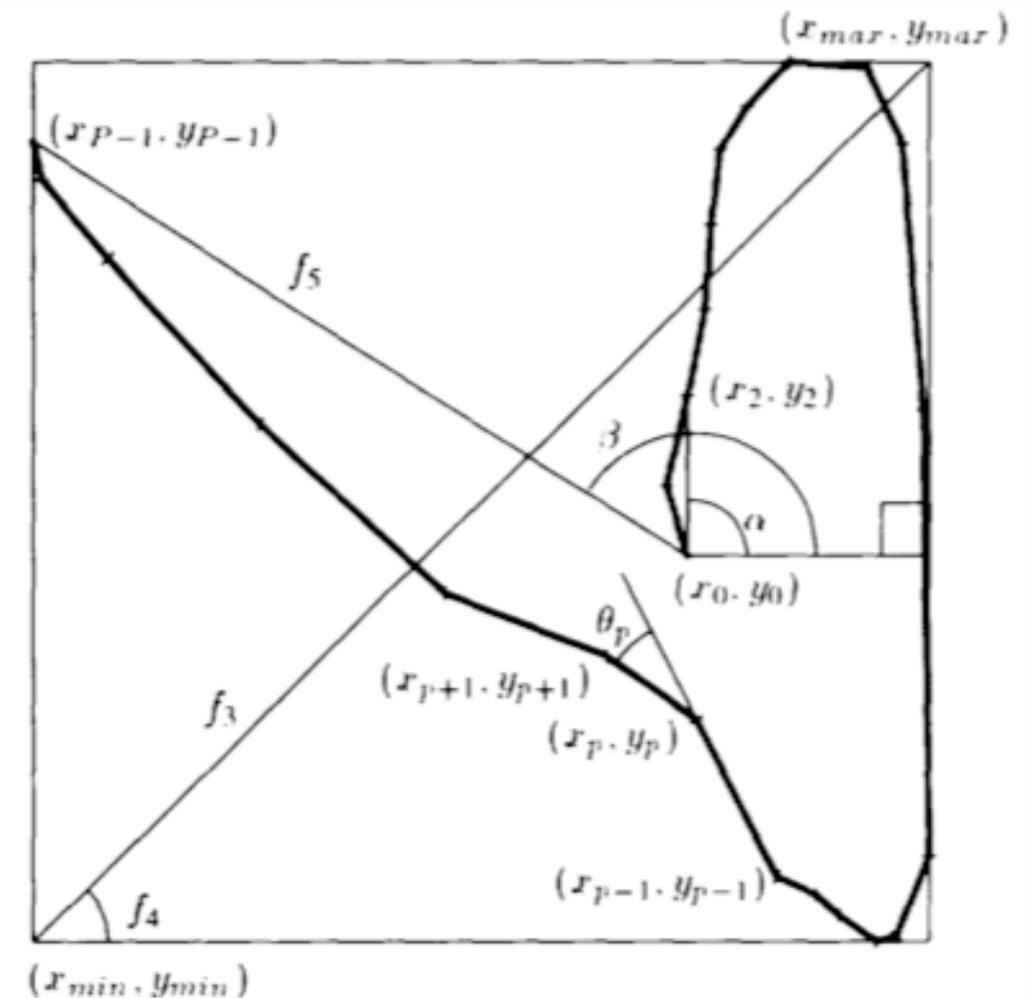
Rubine

Liste de points en entrée

- ▶ Élimination des points trop proches.
 - $d < 3$ pixels du point précédent
- ▶ Calcul d'un vecteur de caractéristiques statistiques.
- ▶ Comparaison aux gestes de référence.
 - Le geste avec le score le plus grand est renvoyé
- ▶ Détection des gestes ambigus

Caractéristiques

- A. cos de l'angle d'origine
- B. sin de l'angle d'origine
- C. longueur diagonale bounding box
- D. angle diagonale bounding box
- E. distance entre premier et dernier point
- F. cos de l'angle entre le premier et dernier point
- G. sin de l'angle entre le premier et dernier point
- H. longueur totale du tracé
- I. angle total traversé
- J. somme des angles absolus à chaque point
- K. somme des carrés de ces angles
- L. vitesse² maximum du geste
- M. durée du geste



Initialisation

Calcul des statistiques moyennes pour chaque caractéristique de chaque geste

Calcul de la matrice de covariance moyenne de tous les gestes

Objectif : trouver les coefficients pondérateurs des caractéristiques statistiques qui permettent de maximiser le score des gestes de chaque classe

Reconnaissance

Calcul des caractéristiques du geste candidat

Calcul d'une probabilité de correspondance pour chaque geste de référence

Le geste avec la probabilité la plus importante est choisi

Dynamic Time Warping

DTW

Déformation temporelle dynamique

Déterminer pour chaque élément d'une séquence, le meilleur élément correspondant dans l'autre séquence relativement à un certain voisinage et à une certaine métrique

Complexité polynomiale

Applications

Vidéo, audio, graphique...

Toutes données qui peuvent être transformées en représentation linéaire en fonction du temps (séries temporelles)

Echantillons ordonnés par une étiquette de temps

Reconnaissance vocale

Reconnaissance de gestes off-line et on-line

Alignement de protéines...

Contexte de base

Séquence de référence $R = [r_1, r_2, \dots, r_n]$

Séquence de test $T = [t_1, t_2, \dots, t_m]$

Si $m = n$ alors on peut calculer la distance deux à deux:

$$D = \sum_{i=1}^n \text{distance}(r_i, t_i)$$

Possibilité de calculer la distance euclidienne ou d'utiliser une autre métrique (fonction qui donne un réel)

Plus possible d'utiliser cette méthode dès que $n \neq m$

Attention : les échantillons doivent être équidistants en temps

DTW, une solution: Principe de base

Programmation dynamique

Fonction d'optimisation :

- ▶ Soit $D(i, j)$ la longueur du chemin entre (r_1, t_1) et (r_i, t_j)

Récursion:

- ▶ $D(i, j) = \text{dist}(r_i, t_j) + \min(D(i-1, j), D(i-1, j-1), D(i, j-1))$
- ▶ Condition initiale : $D(1, 1) = \text{dist}(r_0, t_0)$

Distance minimale entre les deux séquences

- ▶ $D(n, m)$

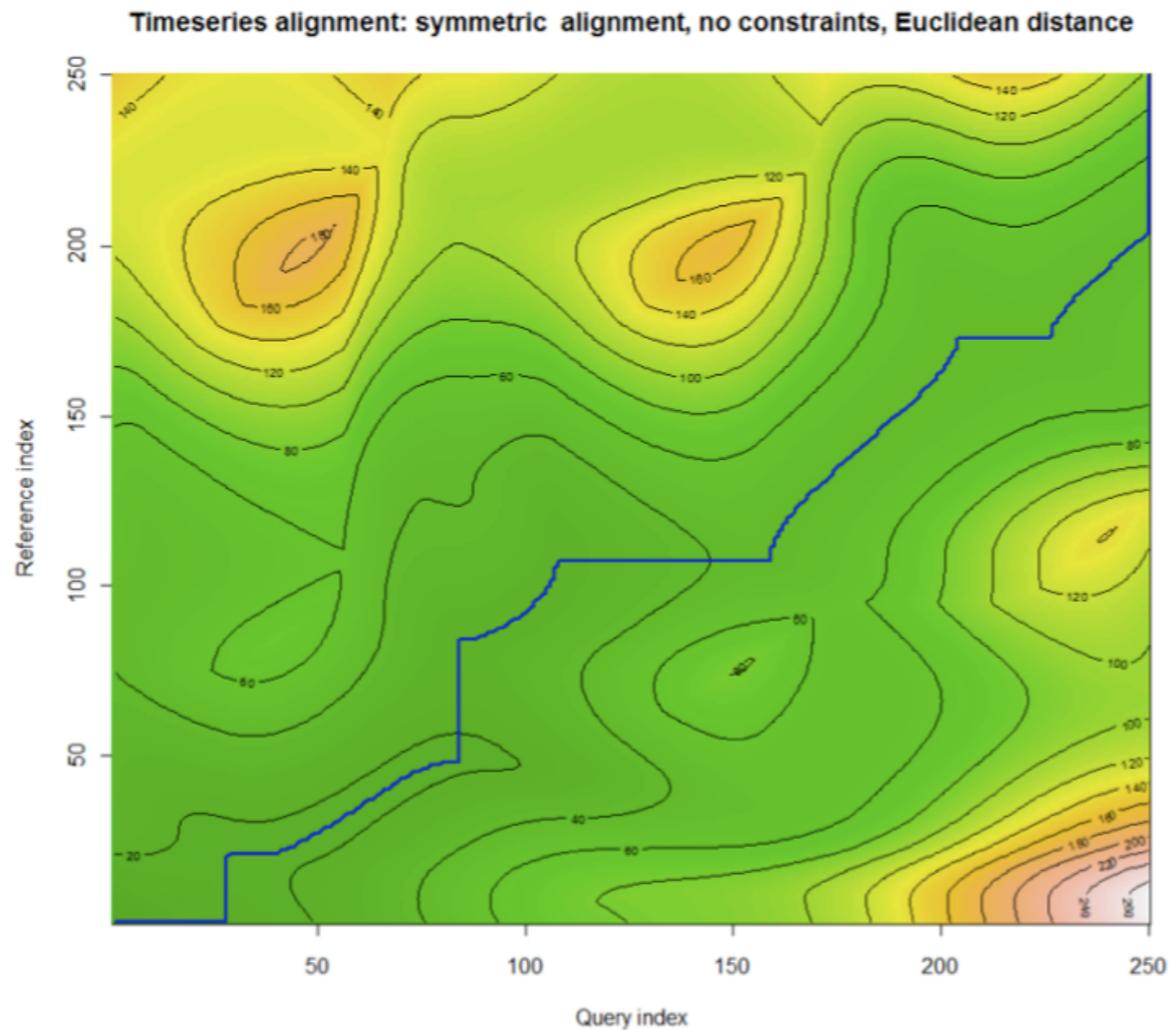
Principe de base

DTW réalise d'abord un alignement non linéaire en recherchant parmi tous les alignements possibles, celui qui minimise une fonction de coût cumulé

« Time Warping » : Dilation ou compression des séquence pour obtenir le meilleur alignement possible

Principe de base

Calcul du chemin $W = [w_1, w_2, \dots, w_k]$ de longueur minimale



$$\sum_{i=1}^k distance(w_i)$$

Principe de base

Conditions aux frontières

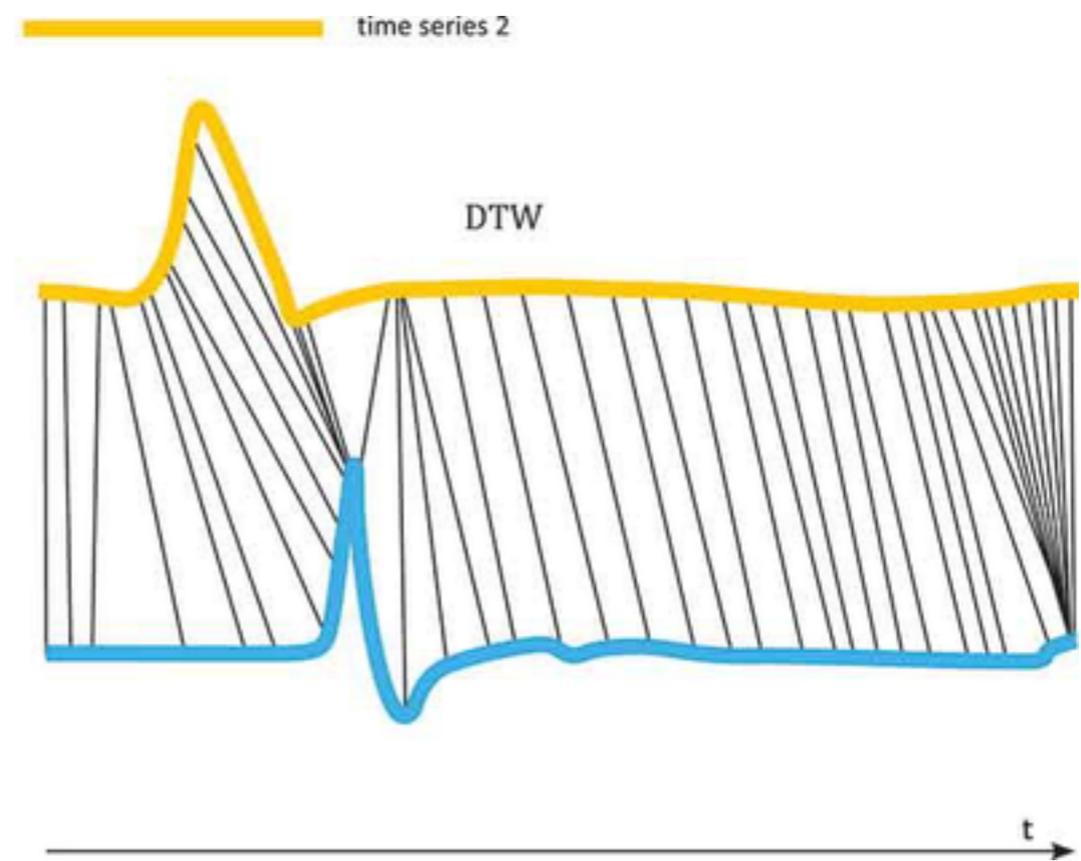
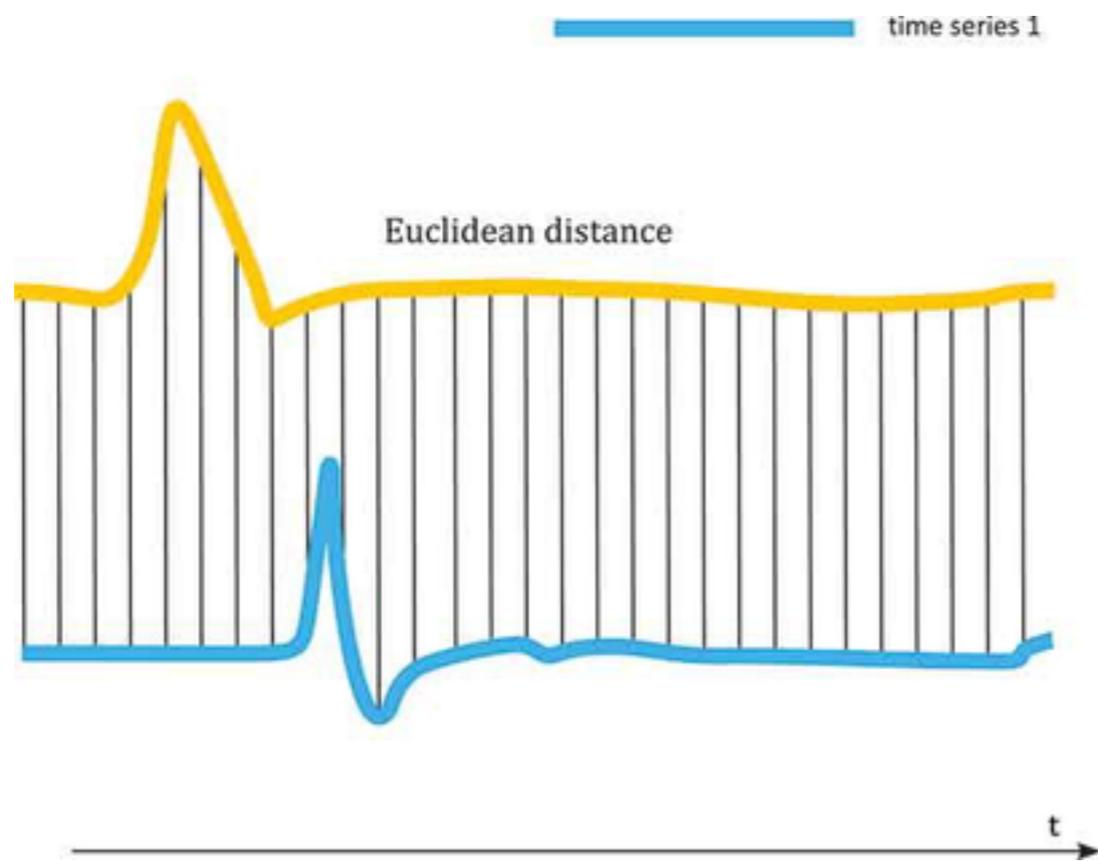
- ▶ $w_1 = (r_1, t_1)$ ou inf
- ▶ $w_k = (r_n, t_m)$ ou inf

Contraintes locales

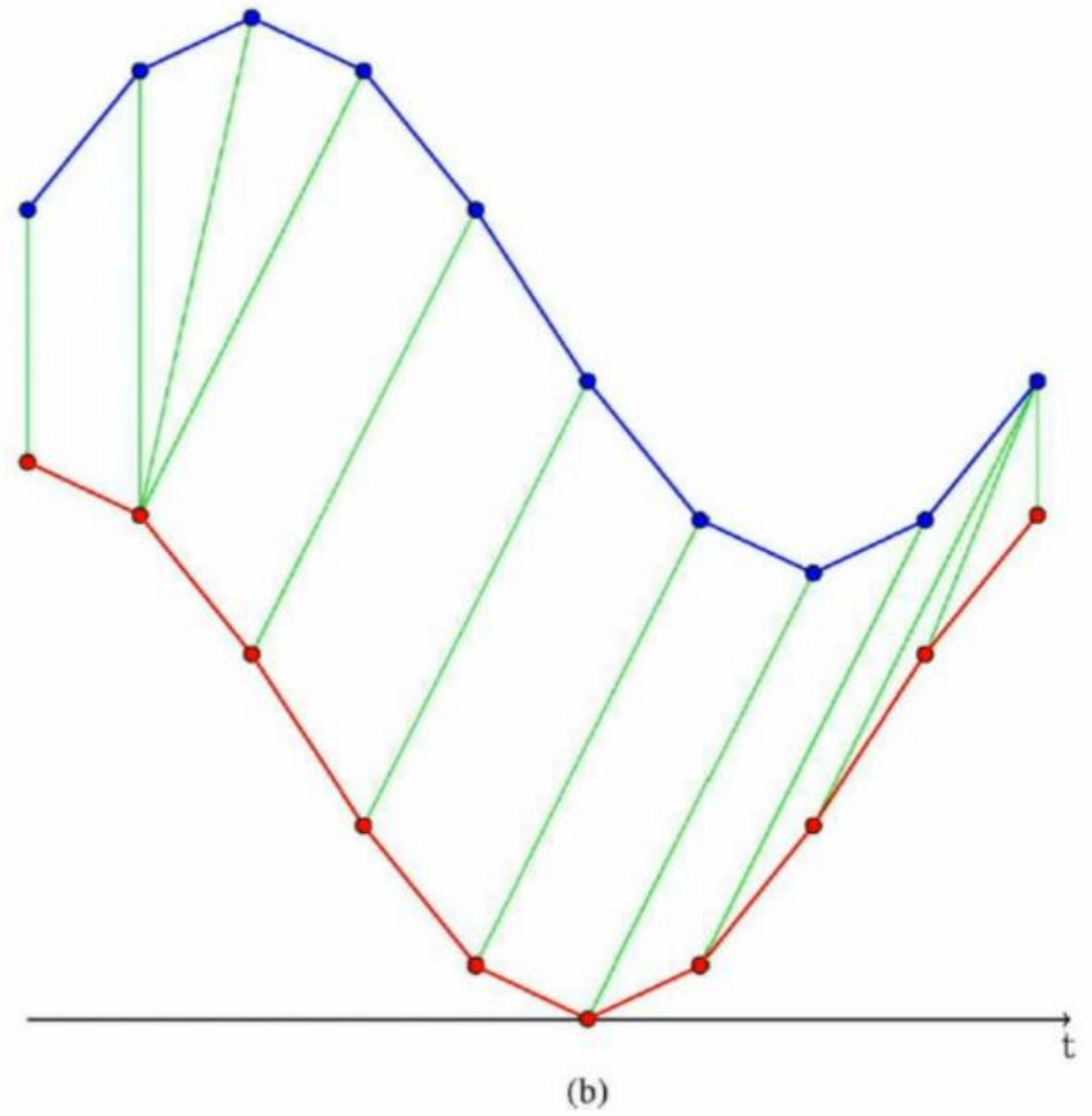
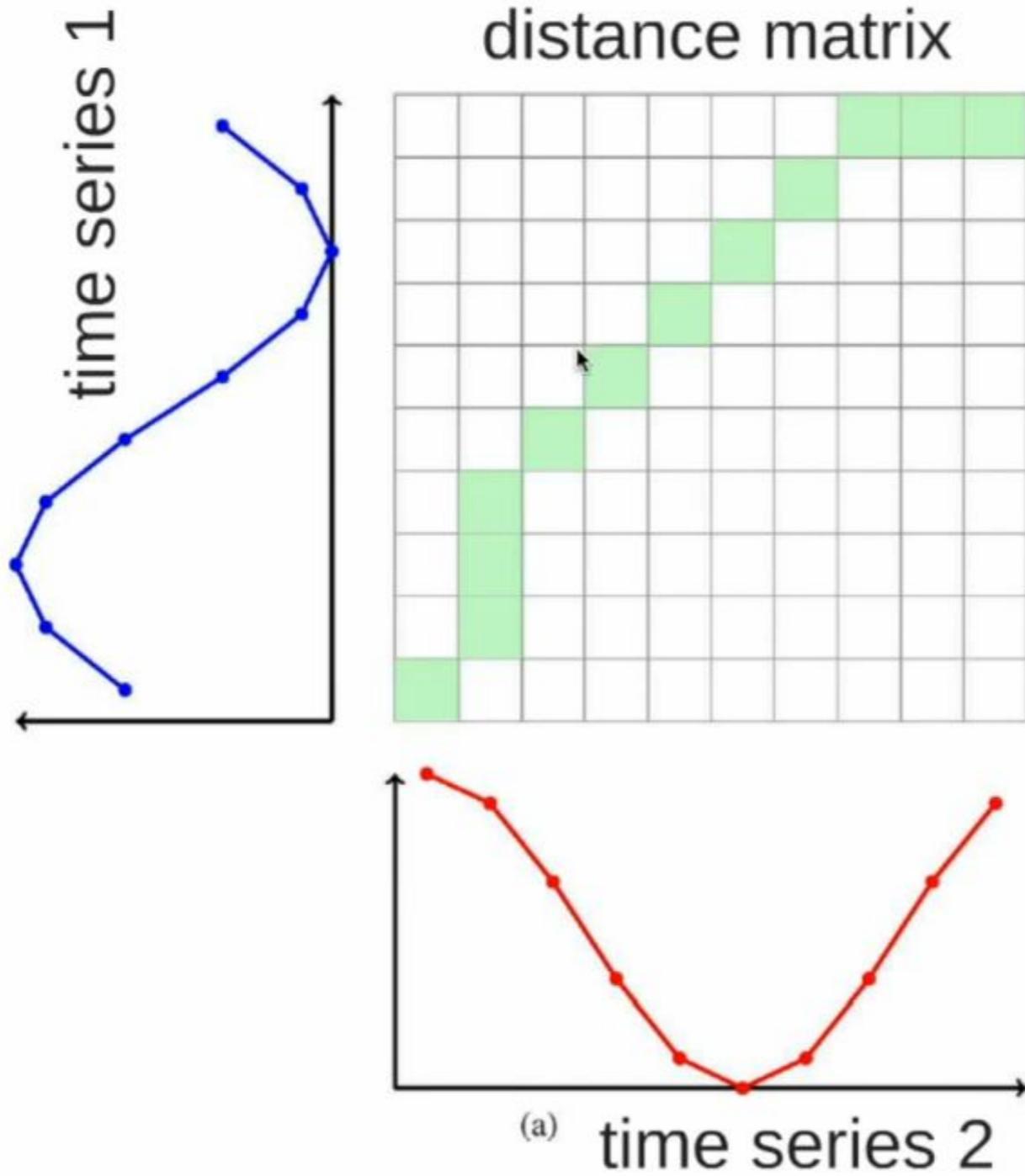
- ▶ Monotonie pour respecter le séquençage des points
- ▶ Éviter les sauts dans le temps
- ▶ Pour tout couple (r_i, t_j) , le choix des prédécesseurs est limité à (r_{i-1}, t_j) , (r_i, t_{j-1}) , (r_{i-1}, t_{j-1})

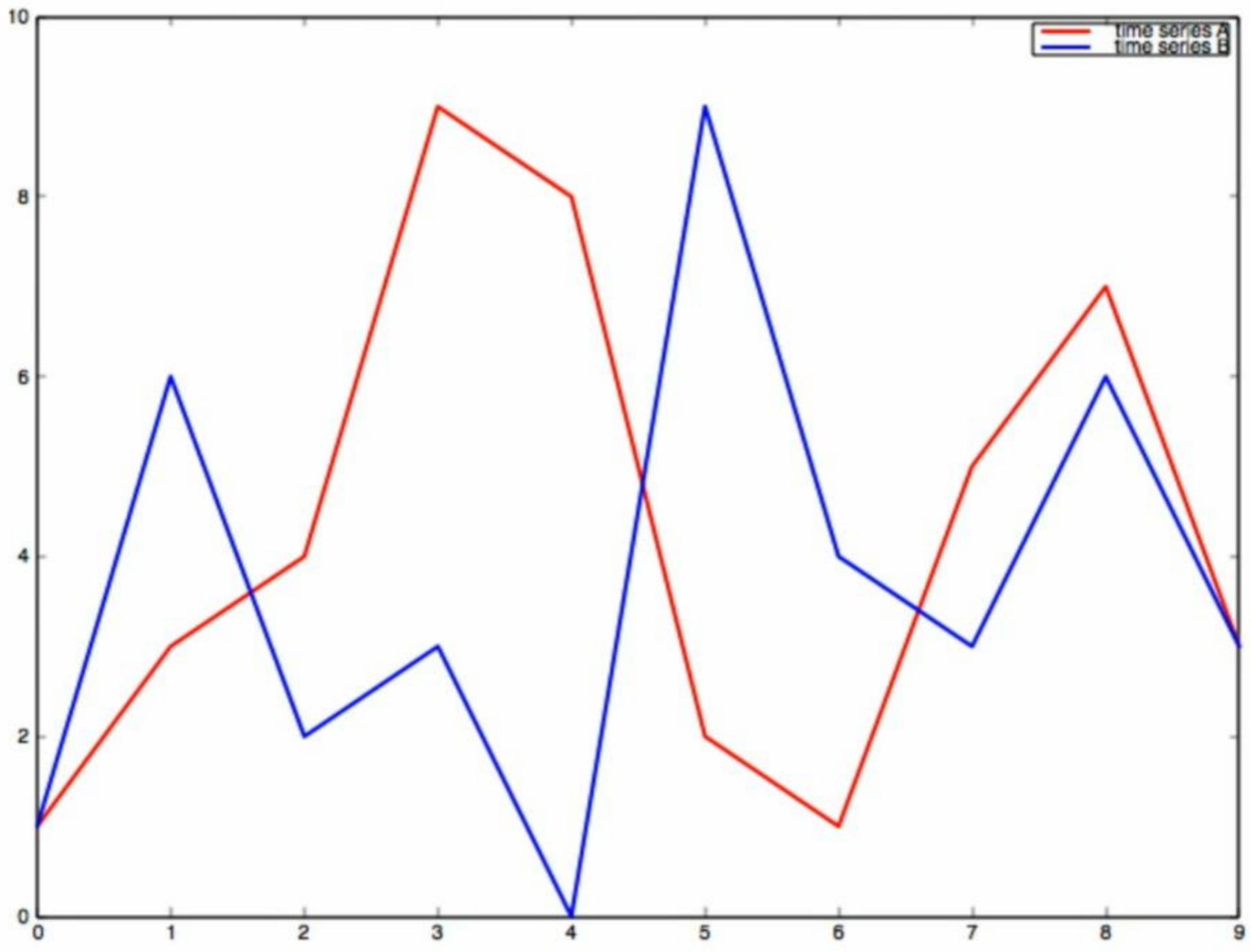
Exhaustivité

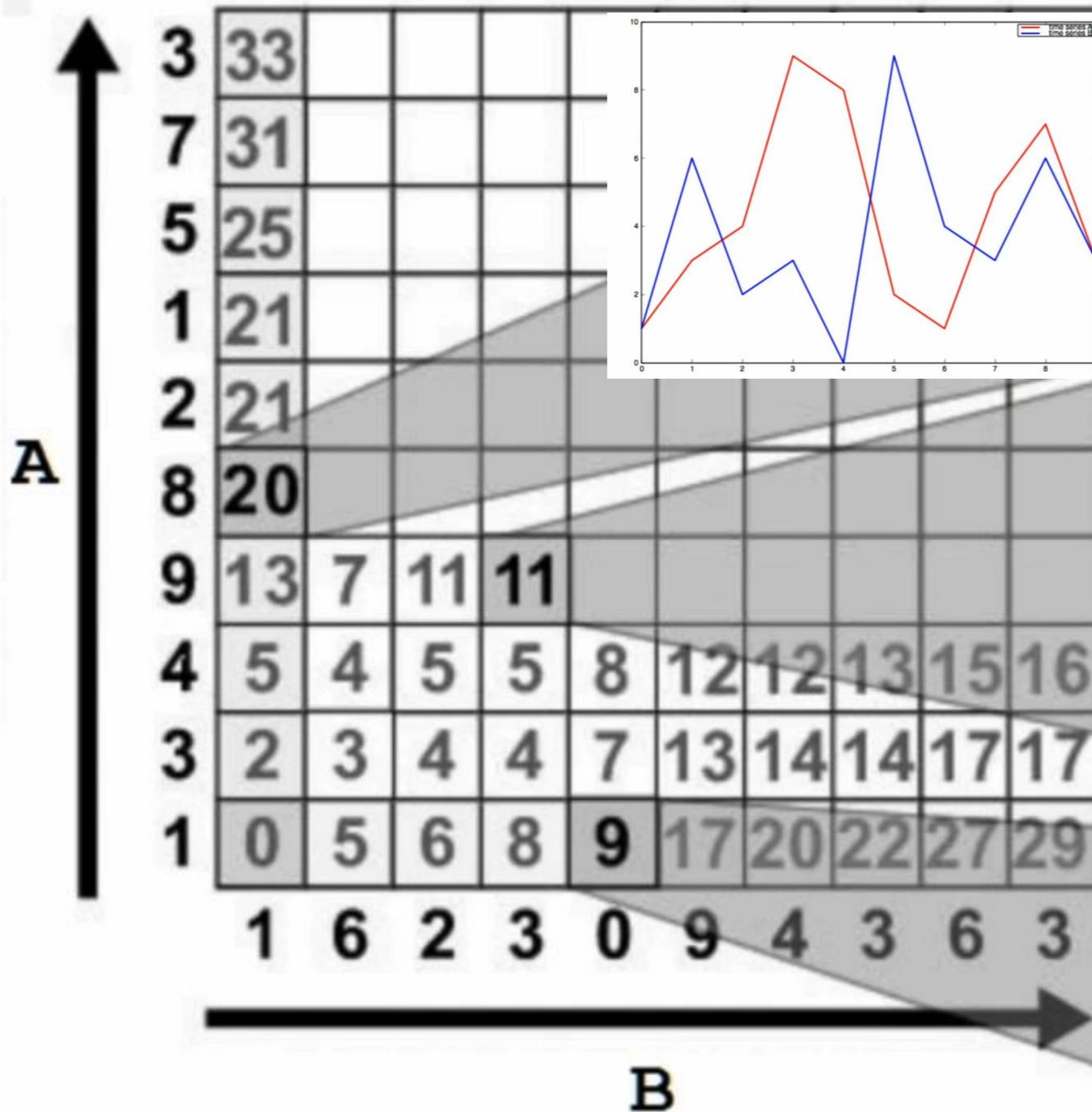
- ▶ Chaque élément de R doit être mis en relation avec au moins un élément de T et vice-versa
- ▶ $\max(m, n) \leq k \leq m + n - 1$



Principe de base



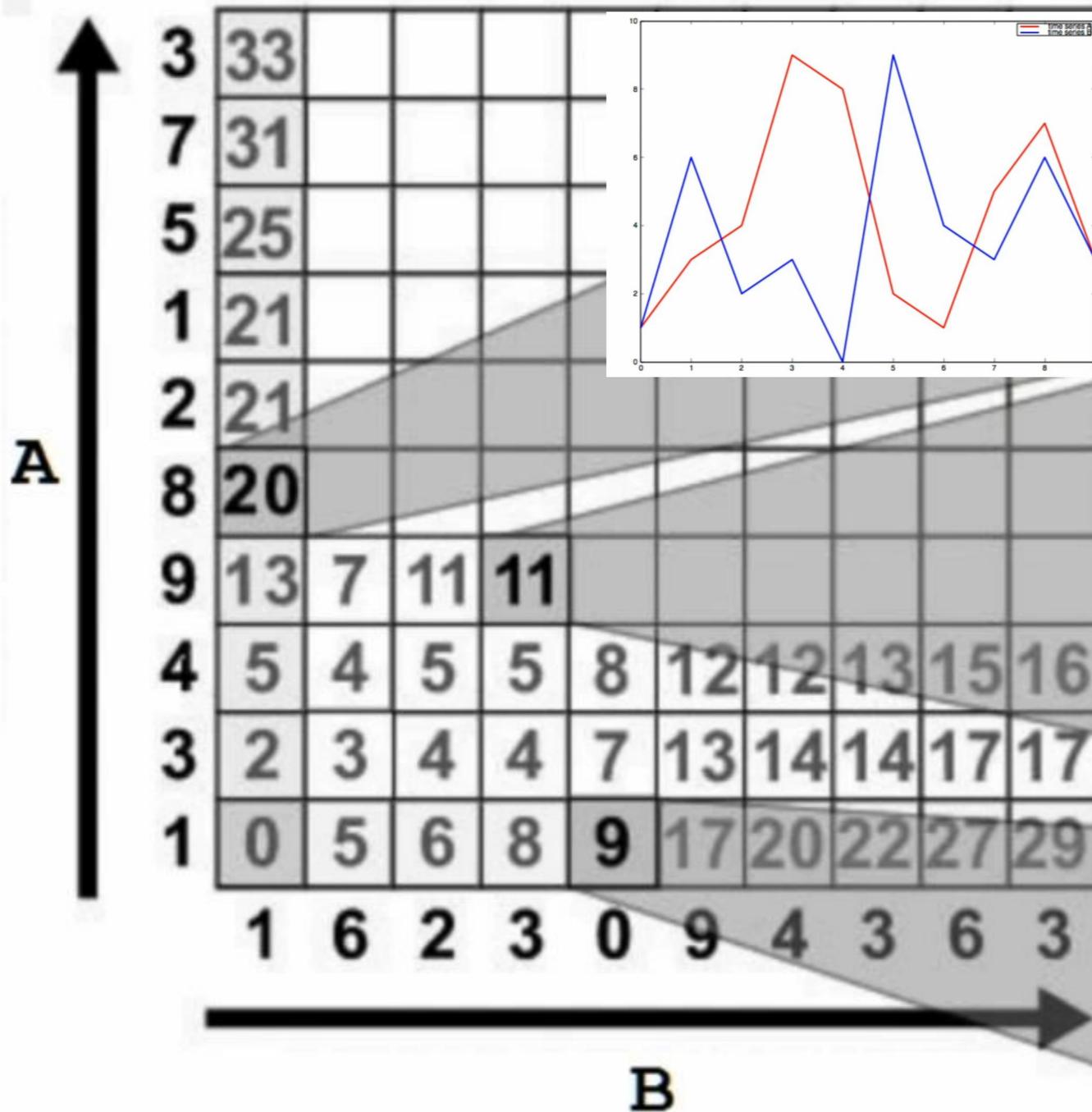




$$\begin{aligned}
 &= |A_i - B_j| + D[i-1, 0] \\
 &= |8 - 1| + 13 \\
 &= 20
 \end{aligned}$$

$$\begin{aligned}
 &= |A_i - B_j| + \min(D[i-1, j-1], \\
 &\quad D[i-1, j], \\
 &\quad D[i, j-1]) \\
 &= |9 - 3| + \min(5, 5, 11) \\
 &= 6 + 5 \\
 &= 11
 \end{aligned}$$

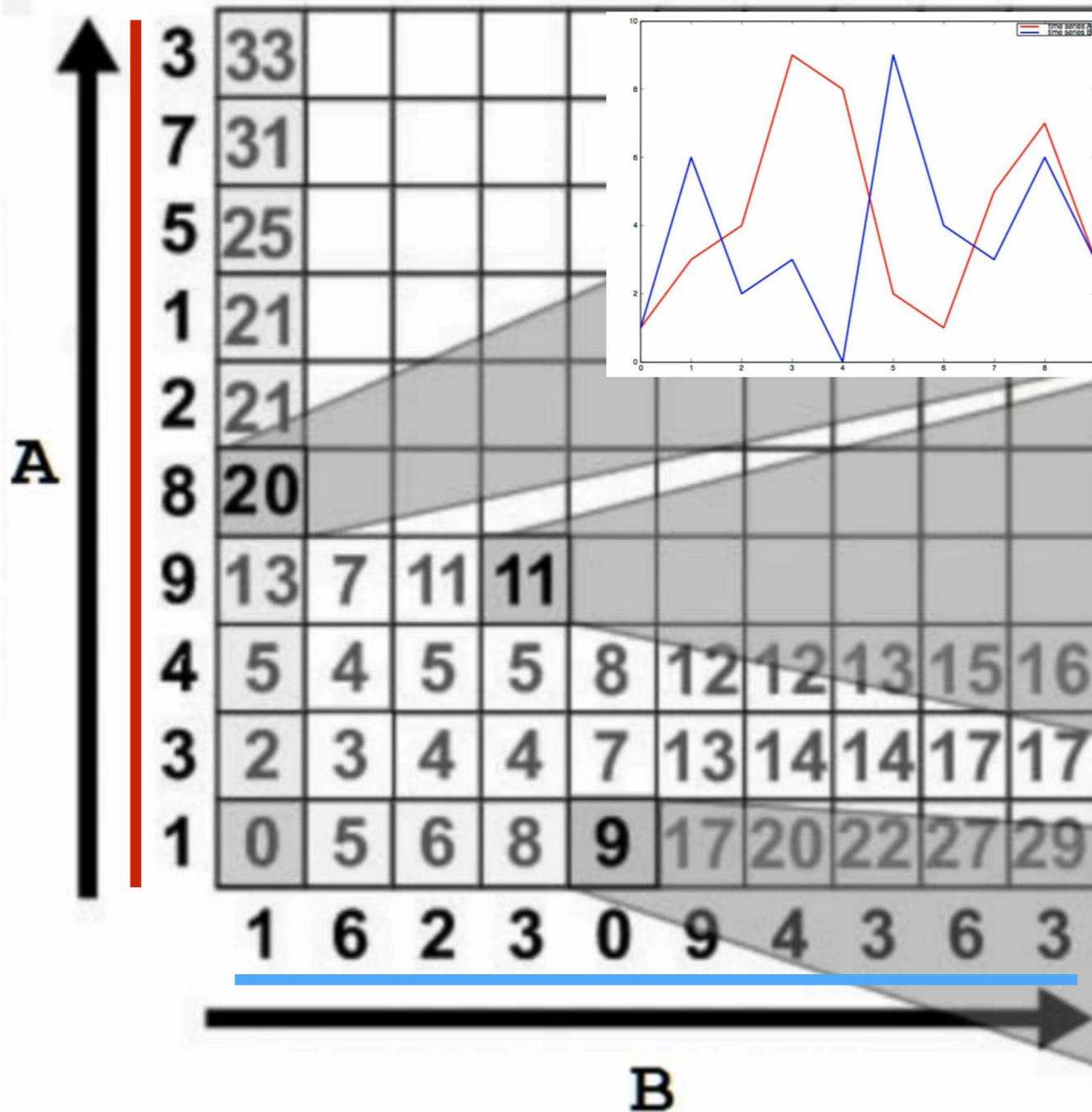
$$\begin{aligned}
 &= |A_i - B_j| + D[0, j-1] \\
 &= |1 - 0| + 8 \\
 &= 9
 \end{aligned}$$



$$\begin{aligned}
 &= |A_i - B_j| + D[i-1, 0] \\
 &= |8 - 1| + 13 \\
 &= 20
 \end{aligned}$$

$$\begin{aligned}
 &= |A_i - B_j| + \min(D[i-1, j-1], \\
 &\quad D[i-1, j], \\
 &\quad D[i, j-1]) \\
 &= |9 - 3| + \min(5, 5, 11) \\
 &= 6 + 5 \\
 &= 11
 \end{aligned}$$

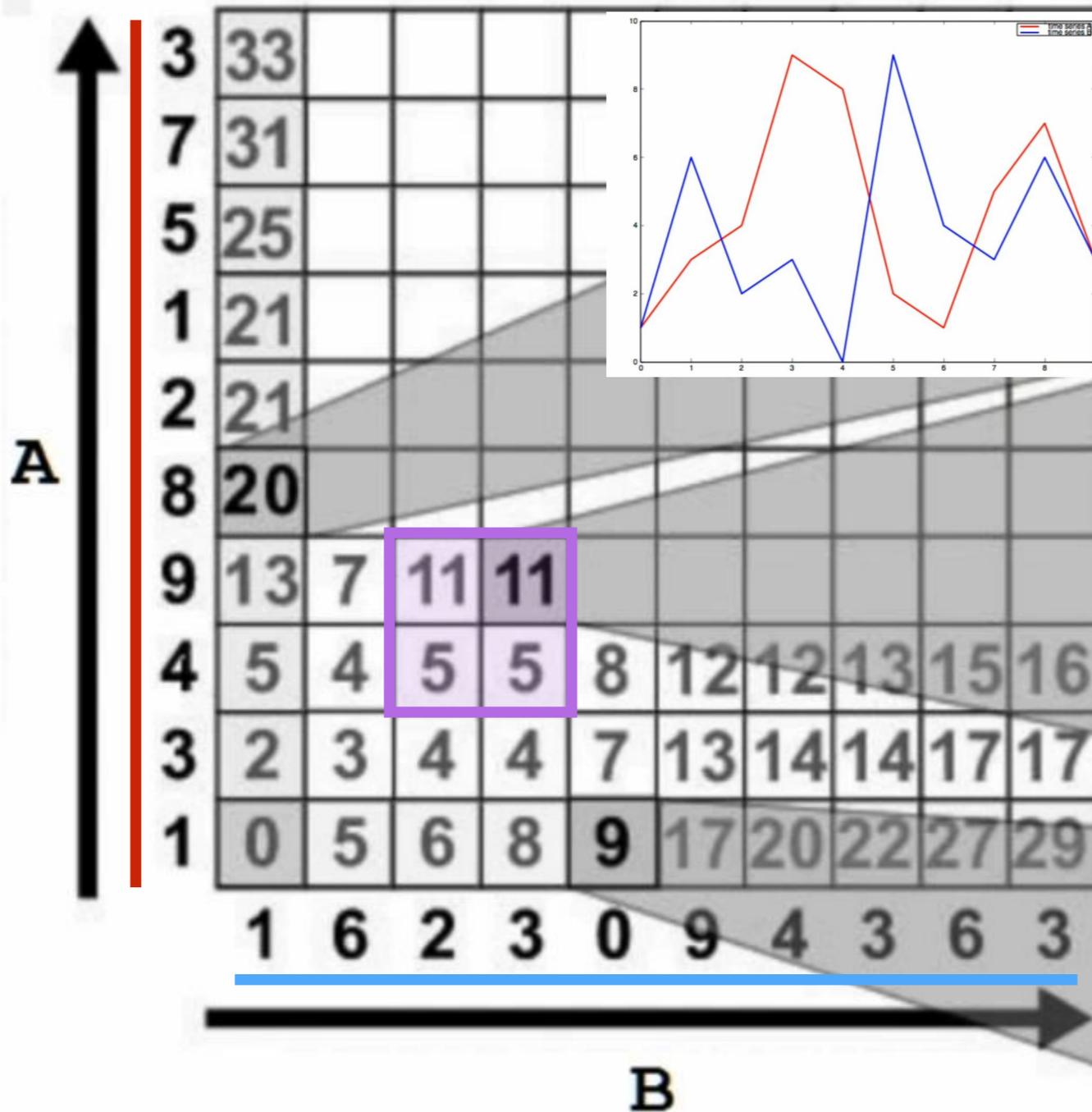
$$\begin{aligned}
 &= |A_i - B_j| + D[0, j-1] \\
 &= |1 - 0| + 8 \\
 &= 9
 \end{aligned}$$



$$\begin{aligned}
 &= |A_i - B_j| + D[i-1, 0] \\
 &= |8 - 1| + 13 \\
 &= 20
 \end{aligned}$$

$$\begin{aligned}
 &= |A_i - B_j| + \min(D[i-1, j-1], \\
 &\hspace{15em} D[i-1, j], \\
 &\hspace{15em} D[i, j-1]) \\
 &= |9 - 3| + \min(5, 5, 11) \\
 &= 6 + 5 \\
 &= 11
 \end{aligned}$$

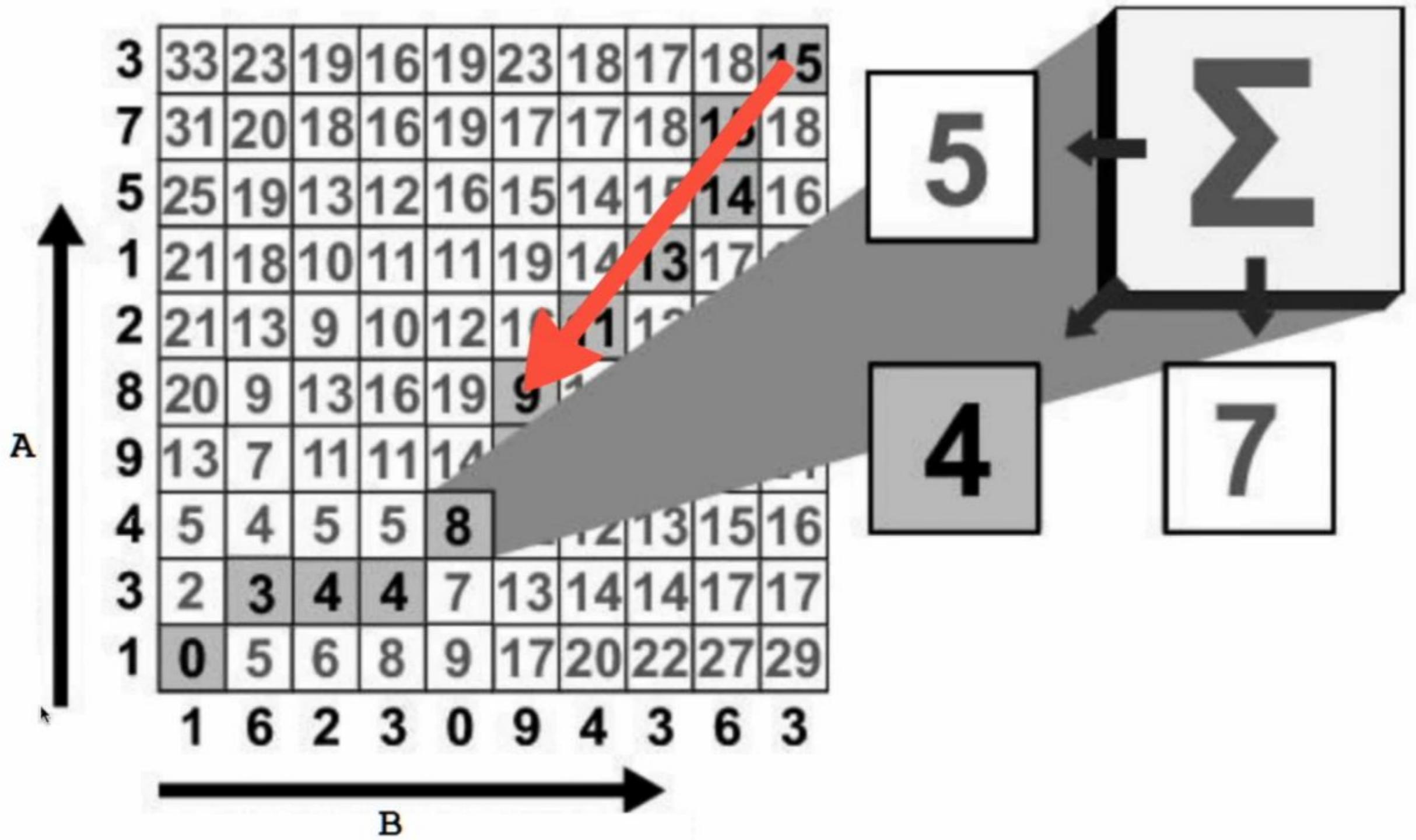
$$\begin{aligned}
 &= |A_i - B_j| + D[0, j-1] \\
 &= |1 - 0| + 8 \\
 &= 9
 \end{aligned}$$

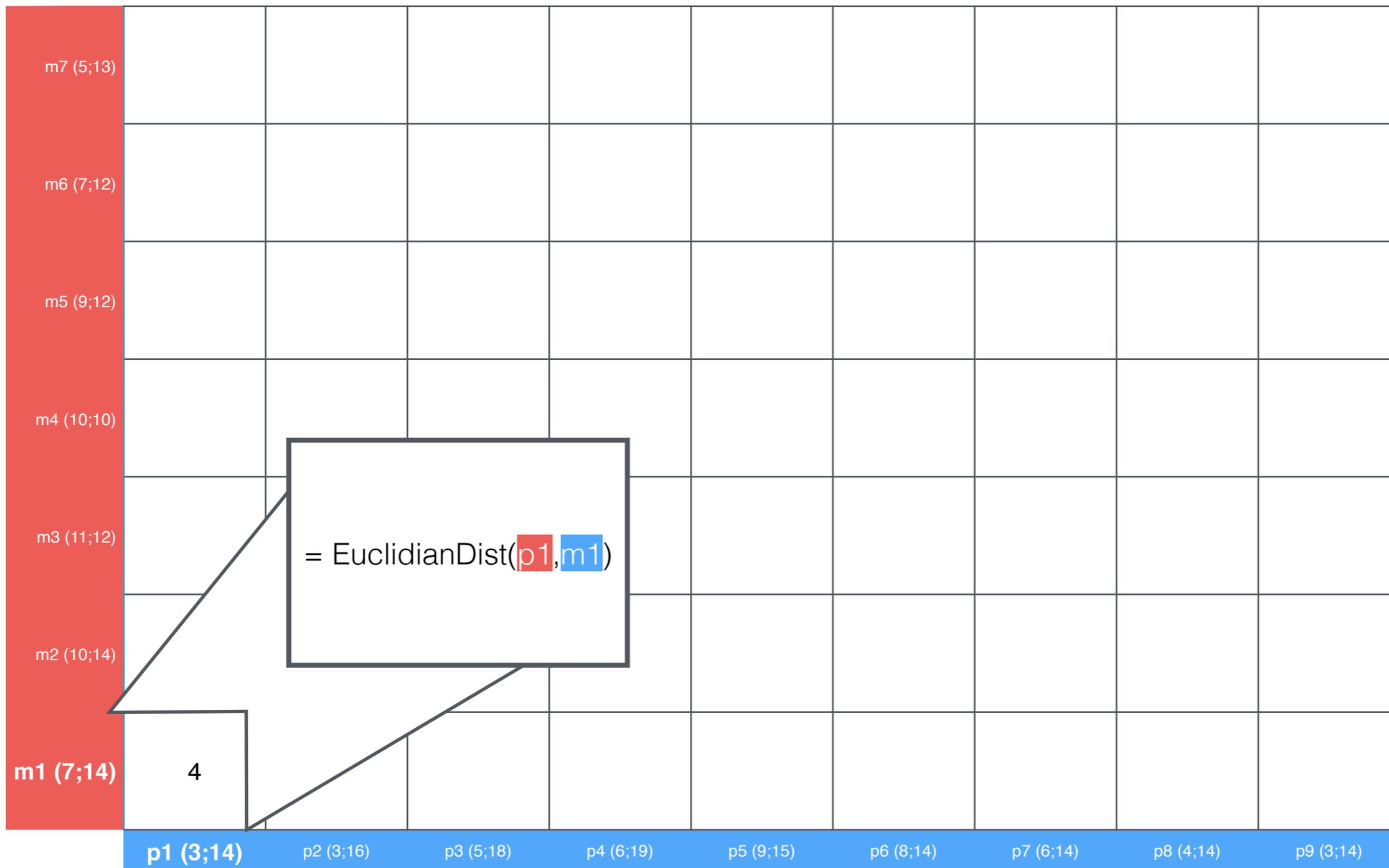


$$\begin{aligned}
 &= |A_i - B_j| + D[i-1, 0] \\
 &= |8 - 1| + 13 \\
 &= 20
 \end{aligned}$$

$$\begin{aligned}
 &= |A_i - B_j| + \min(D[i-1, j-1], \\
 &\quad D[i-1, j], \\
 &\quad D[i, j-1]) \\
 &= |9 - 3| + \min(5, 5, 11) \\
 &= 6 + 5 \\
 &= 11
 \end{aligned}$$

$$\begin{aligned}
 &= |A_i - B_j| + D[0, j-1] \\
 &= |1 - 0| + 8 \\
 &= 9
 \end{aligned}$$





m7 (5;13)	+inf								
m6 (7;12)	+inf								
m5 (9;12)	+inf								
m4 (10;10)	+inf								
m3 (11;12)	+inf								
m2 (10;14)	+inf								
m1 (7;14)	4	+inf							
	p1 (3;14)	p2 (3;16)	p3 (5;18)	p4 (6;19)	p5 (9;15)	p6 (8;14)	p7 (6;14)	p8 (4;14)	p9 (3;14)

m7 (5;13)	+inf								
m6 (7;12)	+inf								
m5 (9;12)	+inf								
m4 (10;10)	+inf								
m3 (11;12)	+inf								
m2 (10;14)	+inf	11,3							
m1 (7;14)	4	+inf	+inf	+inf	+inf	+inf	+inf	+inf	+inf
	p1 (3;14)	p2 (3;16)	p3 (5;18)	p4 (6;19)	p5 (9;15)	p6 (8;14)	p7 (6;14)	p8 (4;14)	p9 (3;14)

$$= \text{EuclidianDist}(p2, m2) + \min(D[i-1, j-1], D[i-1, j], D[i, j-1])$$

$$= 4 + 7,3 = \mathbf{11,3}$$

m7 (5;13)	+inf	45,8	47,2	48,8	40,7	38,0	36,2	37,2	39,4
m6 (7;12)	+inf	42,2	42,7	43,4	36,2	34,8	35,8	39,4	43,9
m5 (9;12)	+inf	36,6	36,4	36,8	32,6	33,6	35,8	40,1	46,4
m4 (10;10)	+inf	29,4	29,2	29,6	31,4	32,2	34,7	40,1	46,8
m3 (11;12)	+inf	20,2	19,8	26,3	27,7	29,1	32,9	38,8	45,7
m2 (10;14)	+inf	11,3	17,7	24,1	25,5	27,5	31,5	37,5	44,5
m1 (7;14)	4	+inf							
	p1 (3;14)	p2 (3;16)	p3 (5;18)	p4 (6;19)	p5 (9;15)	p6 (8;14)	p7 (6;14)	p8 (4;14)	p9 (3;14)

m7 (5;13)	+inf	45,8	47,2	48,8	40,7	38,0	36,2	37,2	39,4
m6 (7;12)	+inf	42,2	42,7	43,4	36,2	34,8	35,8	39,4	43,9
m5 (9;12)	+inf	36,6	36,4	36,8	32,6	33,6	35,8	40,1	46,4
m4 (10;10)	+inf	29,4	29,2	29,6	31,4	32,2	34,7	40,1	46,8
m3 (11;12)	+inf	20,2	19,8	26,3	27,7	29,1	32,9	38,8	45,7
m2 (10;14)	+inf	11,3	17,7	24,1	25,5	27,5	31,5	37,5	44,5
m1 (7;14)	4	+inf							
	p1 (3;14)	p2 (3;16)	p3 (5;18)	p4 (6;19)	p5 (9;15)	p6 (8;14)	p7 (6;14)	p8 (4;14)	p9 (3;14)

m7 (5;13)	+inf	45,8	47,2	48,8	40,7	38,0	36,2	37,2	39,4
m6 (7;12)	+inf	42,2	42,7	43,4	36,2	34,8	35,8	39,4	43,9
m5 (9;12)	+inf	36,6	36,4	36,8	32,6	33,6	35,8	40,1	46,4
m4 (10;10)	+inf	29,4	29,2	29,6	31,4	32,2	34,7	40,1	46,8
m3 (11;12)	+inf	20,2	19,8	26,3	27,7	29,1	32,9	38,8	45,7
m2 (10;14)	+inf	11,3	17,7	24,1	25,5	27,5	31,5	37,5	44,5
m1 (7;14)	4	+inf							
	p1 (3;14)	p2 (3;16)	p3 (5;18)	p4 (6;19)	p5 (9;15)	p6 (8;14)	p7 (6;14)	p8 (4;14)	p9 (3;14)