An Eye on Input:
Research Challenges in Using the Eye for Computer Input Control

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http://www.yorku.ca/mack/

Overview

- Eye tracking challenges
- Looking
- Selecting
- Evaluating
- Case study

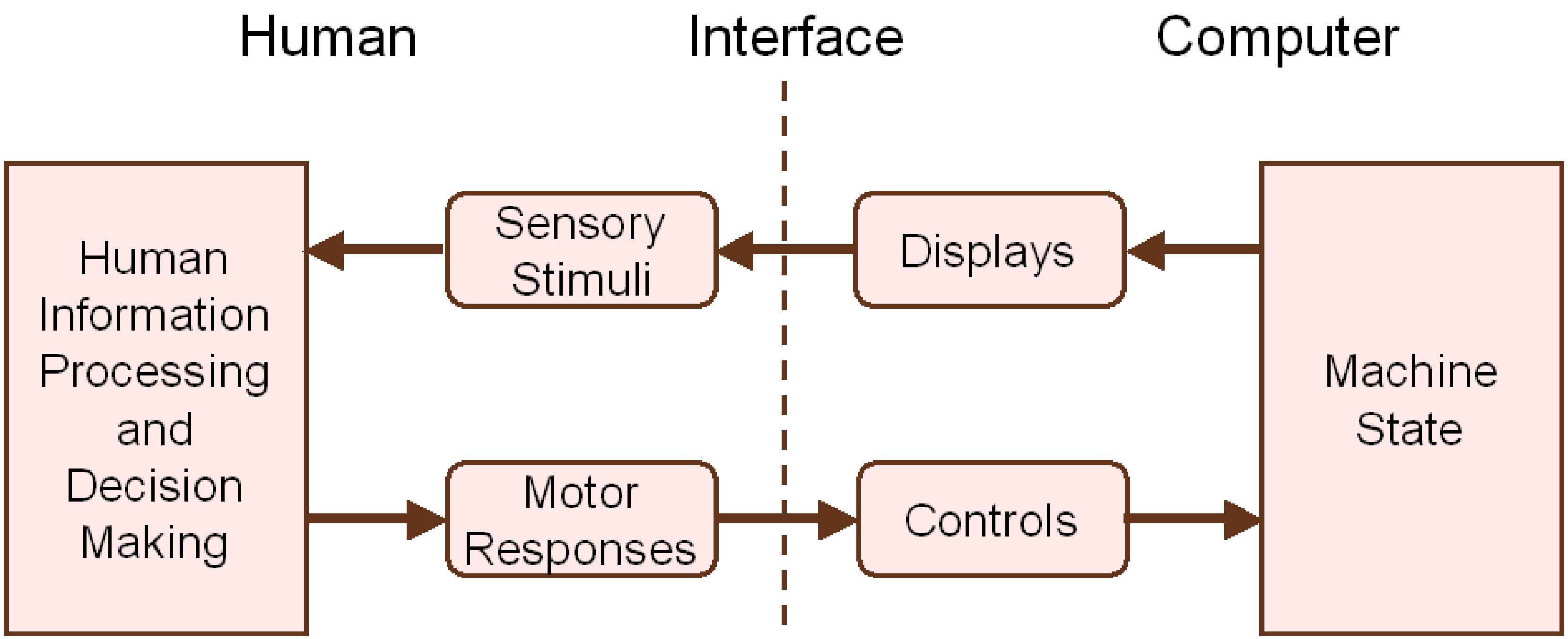
Eye Movement

- Saccades
  - Movement of eye from one place to another
  - Duration: 30-120 ms
  - Range: 1° to 40° visual angle (15° to 20° average)
- Fixation
  - Follows saccade
  - Duration: 200 ms to 600 ms
  - Eye jitter during fixations
    - Small movements (typically < 1° in size)
    - Refresh image
  - Eye drift during fixations
    - Slow random movement away from fixation
    - Corrected with microsaccade

Eye Tracking Challenges

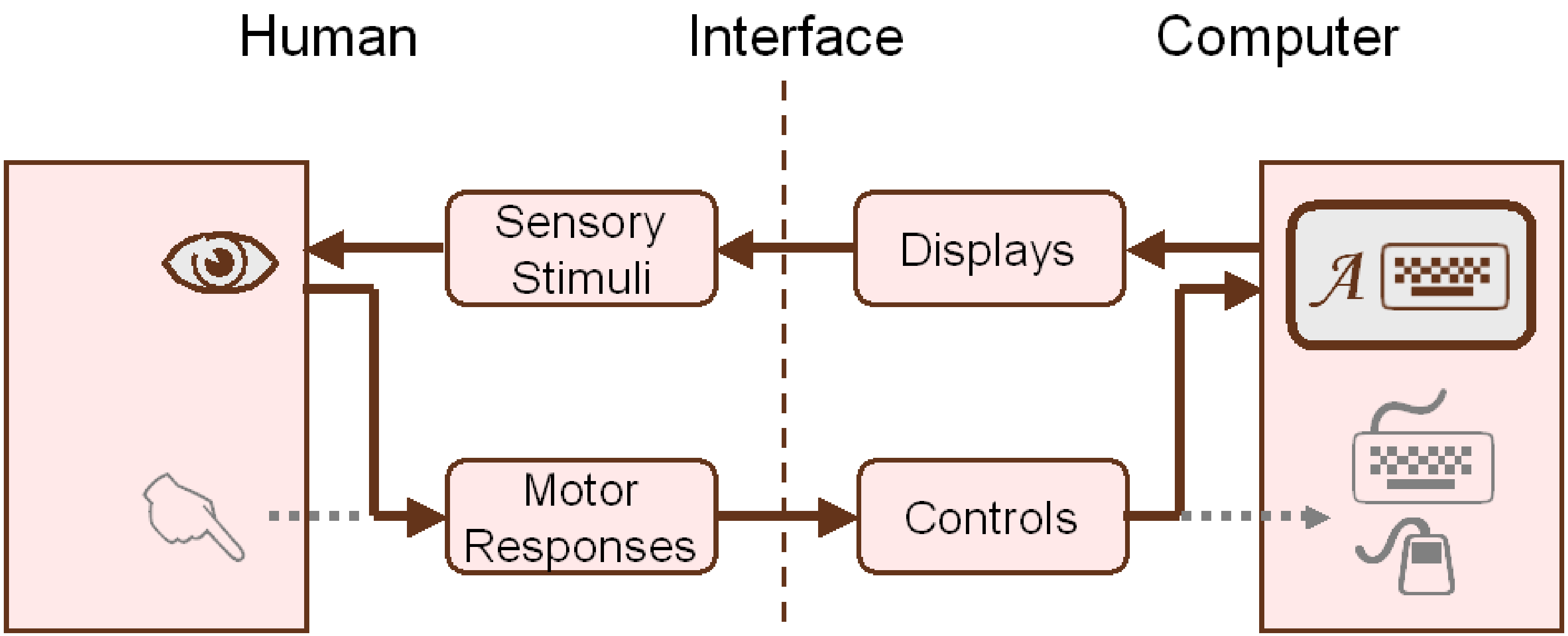
- "It's not about the bike" (Lance Armstrong)
- "It's not about the eye tracker"
- Evaluate the interface, the interaction, the experience, not the eye tracker
- Easier said than done (like speech or handwriting recognition)
- Human-machine interaction

Human-Computer Interface



Using the eye as the input control

"Double Duty"


Human
Interface
Computer
Sensory
Stimuli
Displays
Motor
Responses
Controls

An Eye Tracking Session at *CHI*

Gaze & Eye Tracking
Session Chair: C. North, *Virginia Polytechnic Institute and State University*

Visual search → **407 What Are You Looking For? An Eye-tracking Study of Information Usage in Web Search**
E. Cutrell, *Microsoft Research*
Z. Guan, *University of Washington*

Visual search → **417 An Eye Tracking Study of the Effect of Target Rank on Web Search**
Z. Guan, *University of Washington*
E. Cutrell, *Microsoft Research*

421 EyePoint: Practical Pointing and Selection Using Gaze and Keyboard ← Input control
M. Kumar, A. Paepcke, T. Winograd, *Stanford University*

Visual search → **431 A Minimal Model for Predicting Visual Search in Human-Computer Interaction**
T. Halverson, A. J. Hornof, *University of Oregon*

Two-step Input Control

- Mouse → point-select
- Eye → look-select

    - Where is the user looking?
    - Select it!

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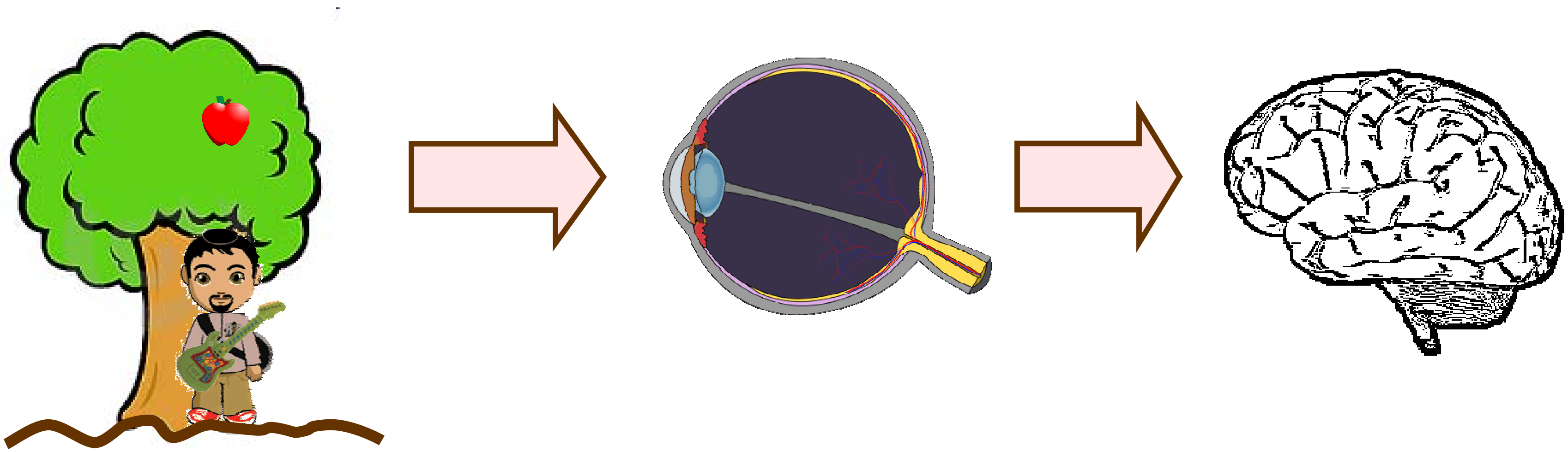
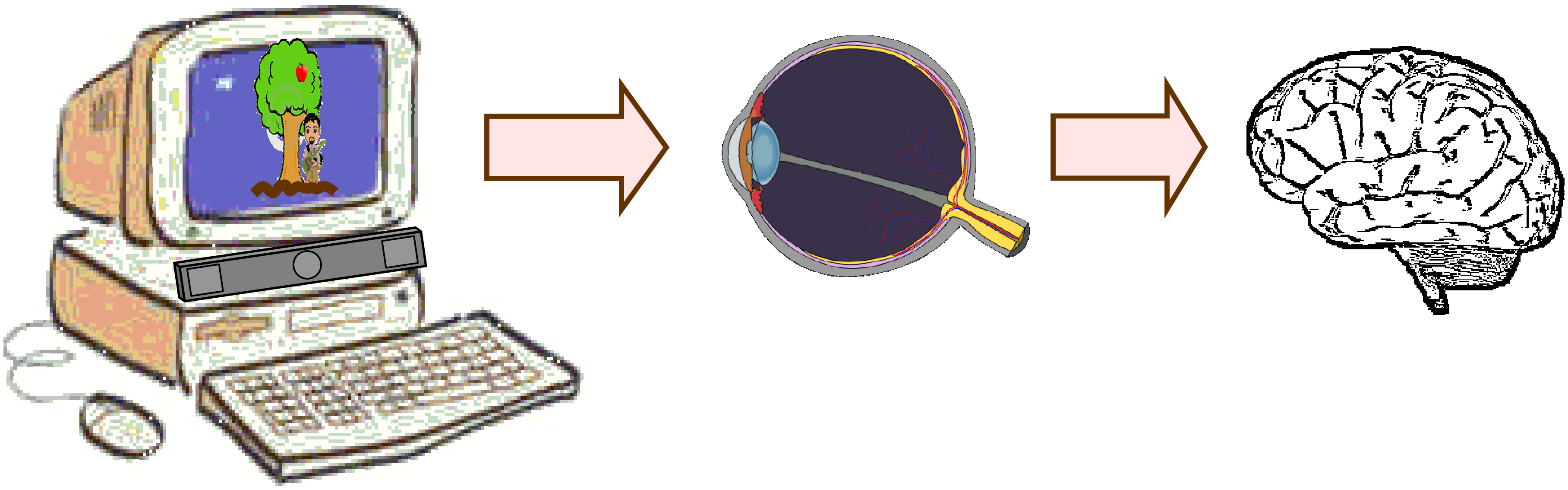
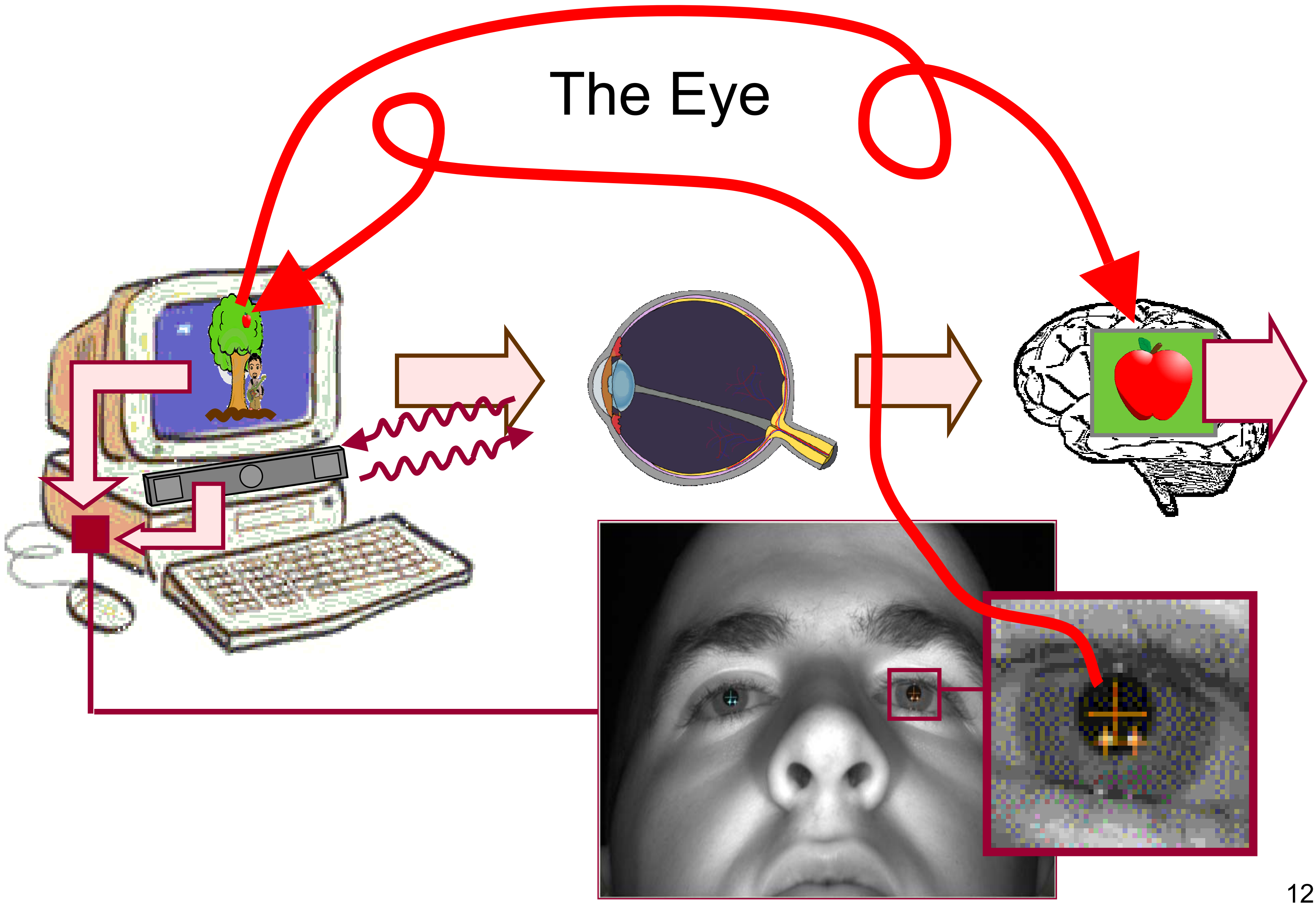
The Eye



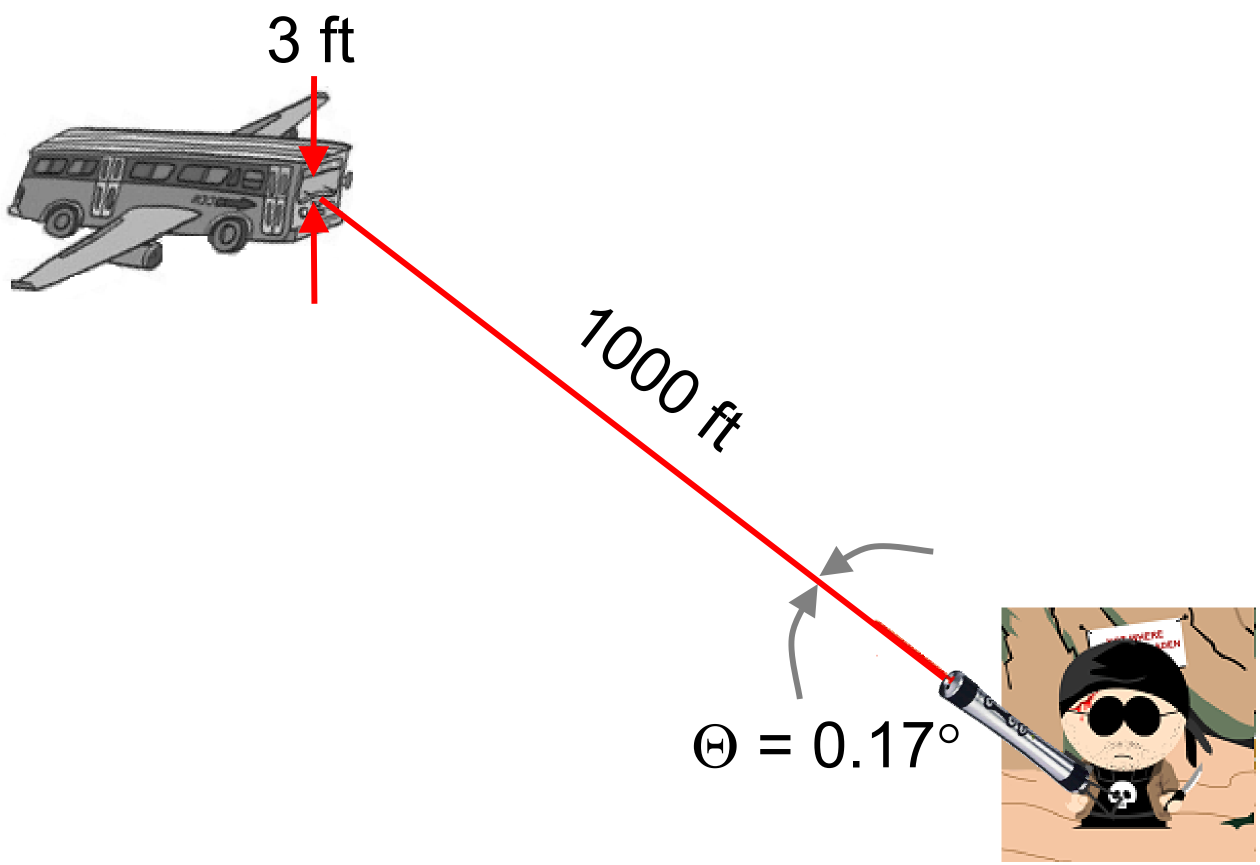
The Eye



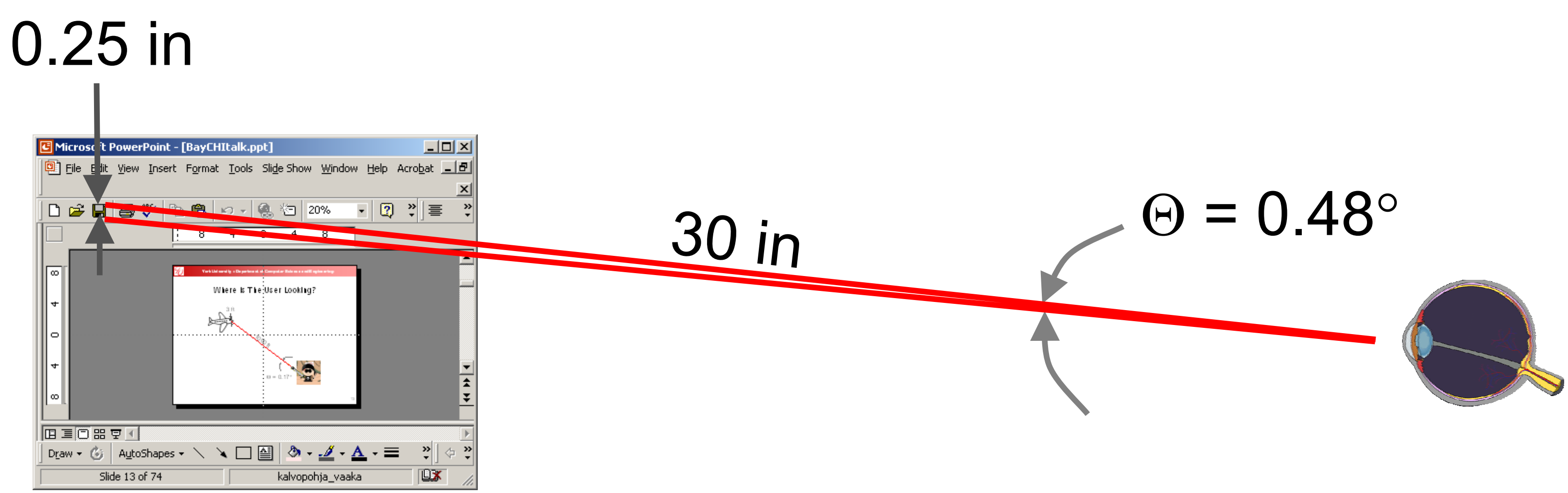
The Eye



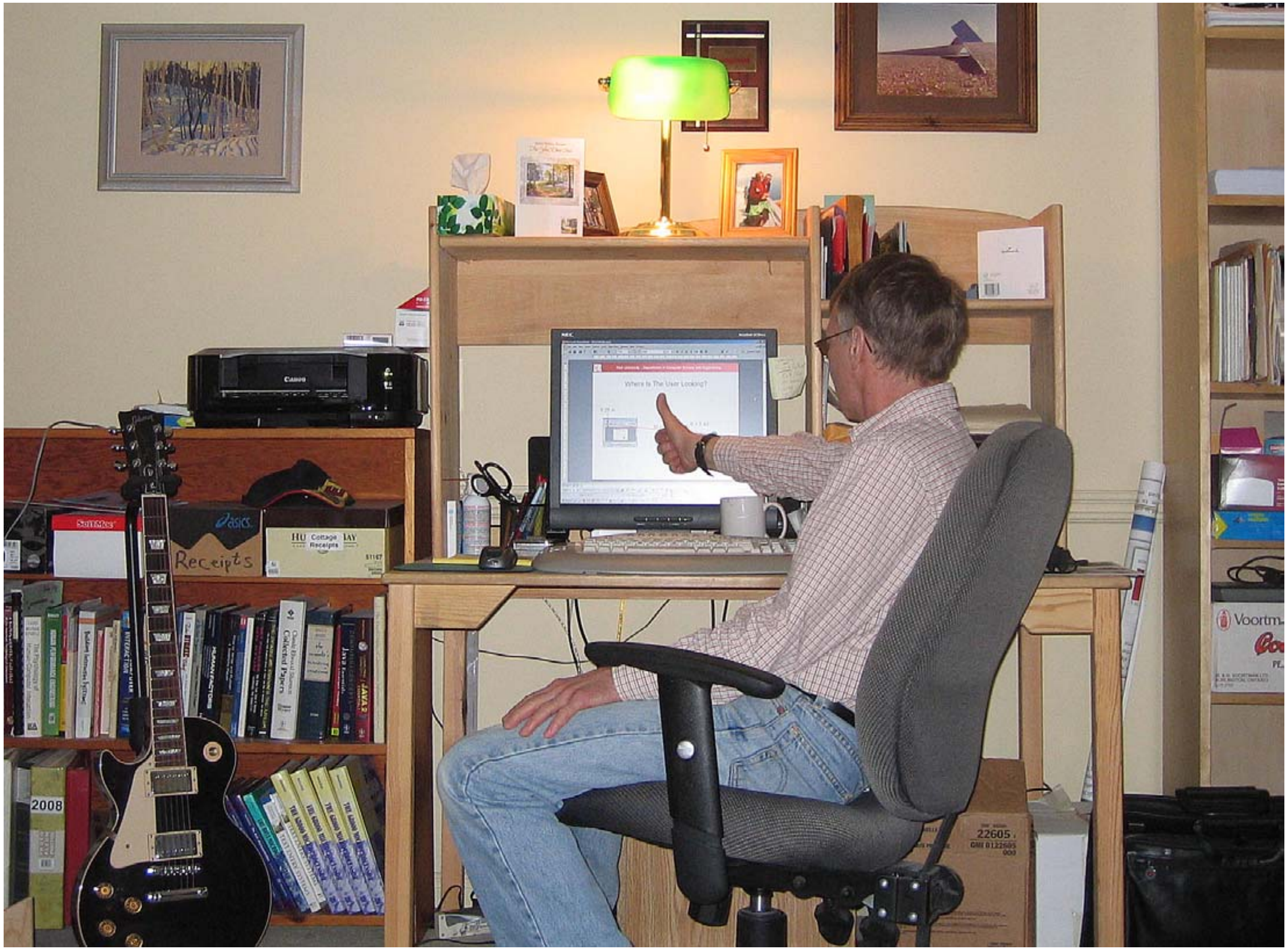
Where Is The User ~~Looking~~ Pointing?



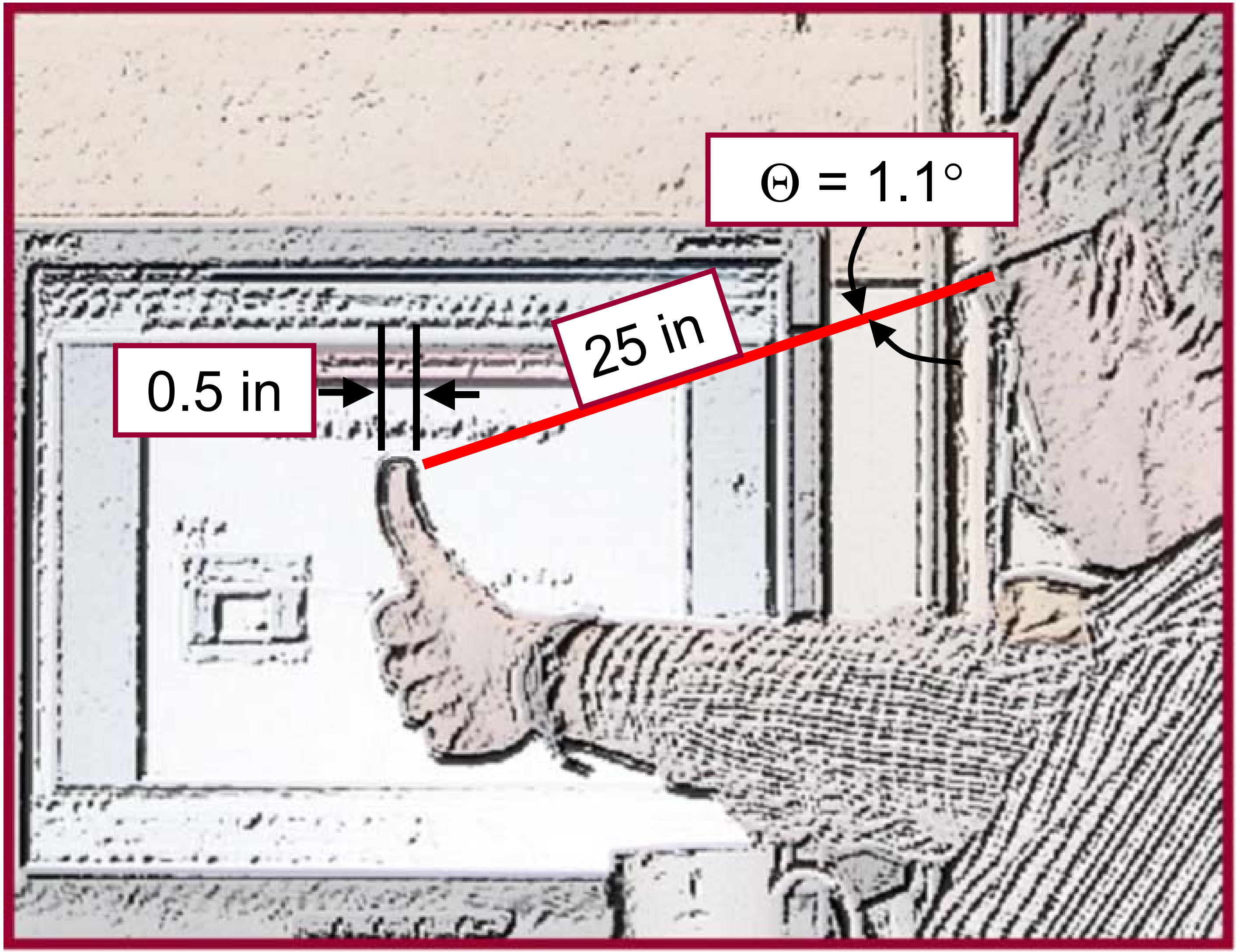
Where Is The User Looking?



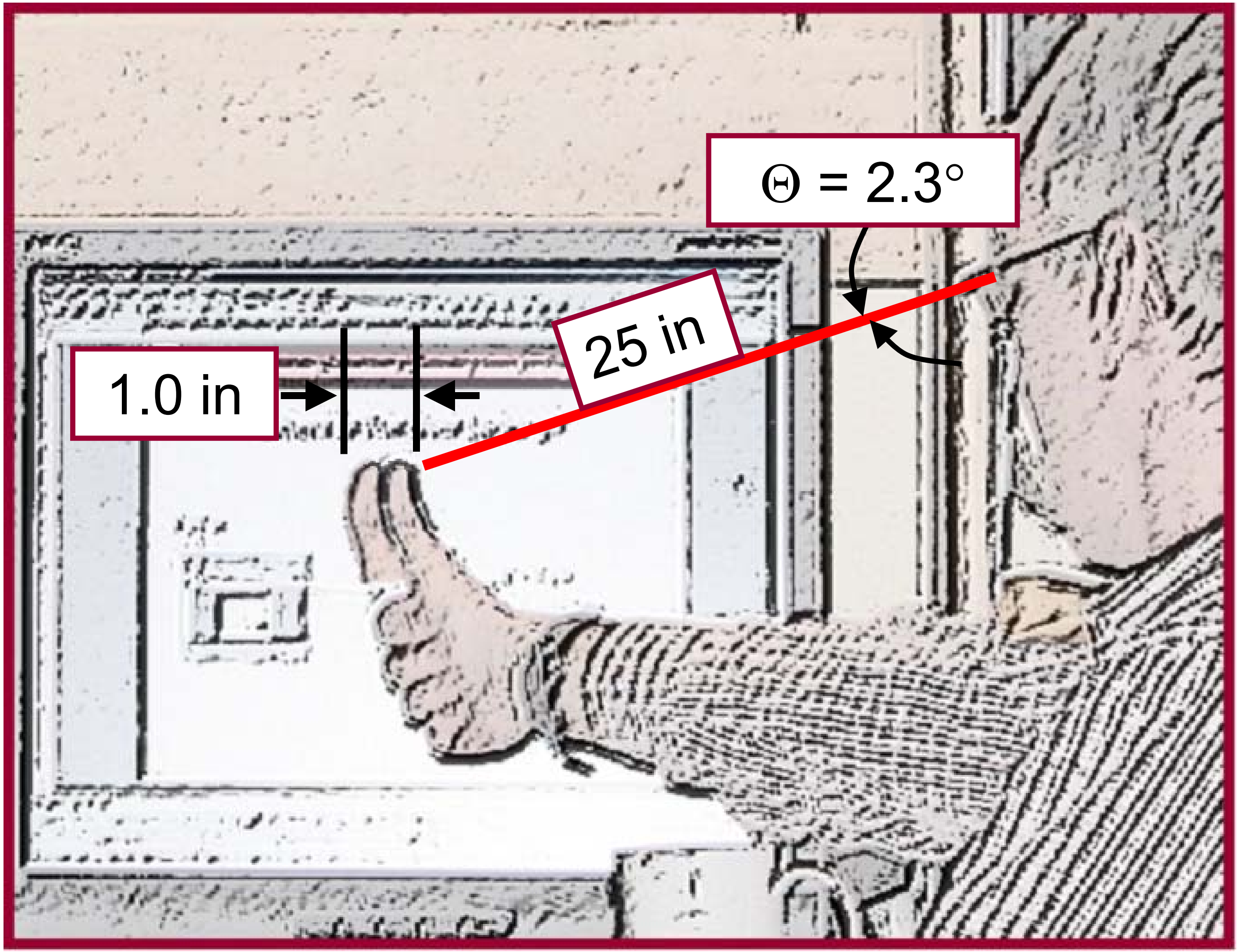
Where Is My Thumb?



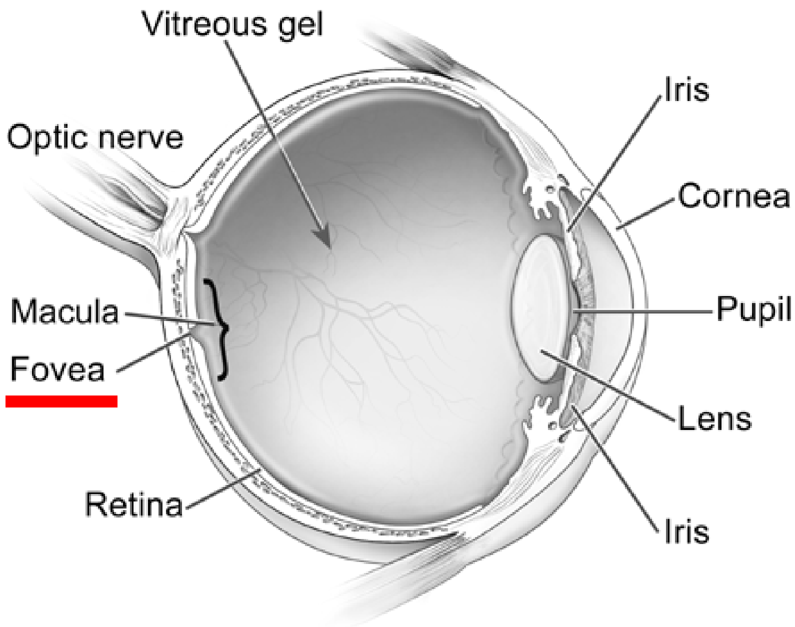
Where Is My Thumb?



Double Trouble!



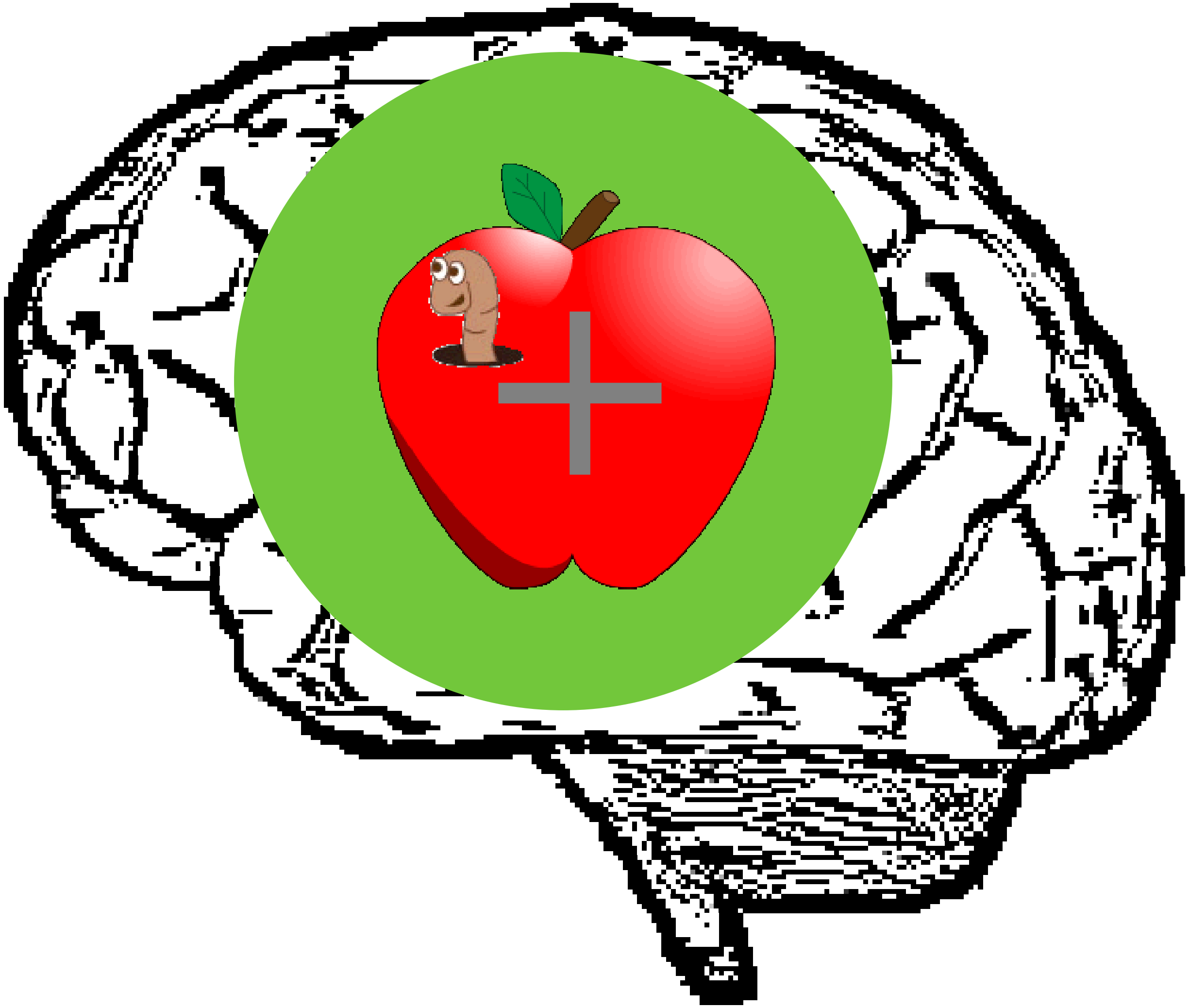
Fovea



- Area of the eye responsible for sharp central vision
- Necessary for reading, driving, sewing, etc.
- 1% of retina, but 50% of visual cortex in brain
- The fovea sees “twice the width of a thumbnail at arms length” (about 2-3 degrees)

Eye tracking relevance: The fovea image represents a “region of uncertainty”

Where is the User Looking?



Demo


DemoFoveaCursor
Microsoft PowerPoint - [ETRA keynote talk.ppt]
ETRA 2010 - Authors - Mozilla Firefox
http://etra.cs.uta.fi/authors.html
ETRA 2010 - Authors
ETRA
Eye Tracking Research & Applicati
22-24 March 2010, Austin,
HOME PROGRAM AUTHORS SPONSORS EXHIBITORS REGISTRATION VENUE
[Call for Papers] [Instructions for Authors] [Instructions for Reviewers]
Call for Papers
Eye Tracking Research & Applications Symposium ETRA 2010
22nd - 24th March 2010, Austin, TX, USA
Call for Participation
Interface
ETRA Web Page
Eye Typing (Large)
Eye Typing (Small)
Gaze Talk
Cursor
Hand
Crosshair
Fovea (1T)
Fovea (2T)
Zoom
Zoom In
Zoom Out
Reset

Two-step Eye Input Control

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- Eye → look-select

  - Where is the user looking?
  - Select it!

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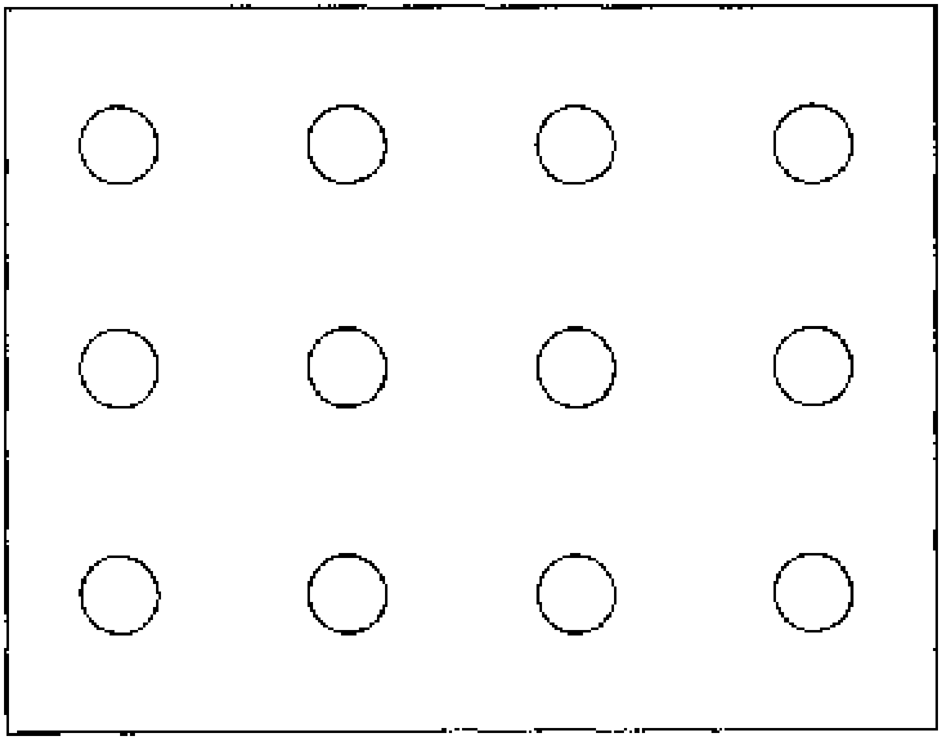
"Smart" Target Acquisition

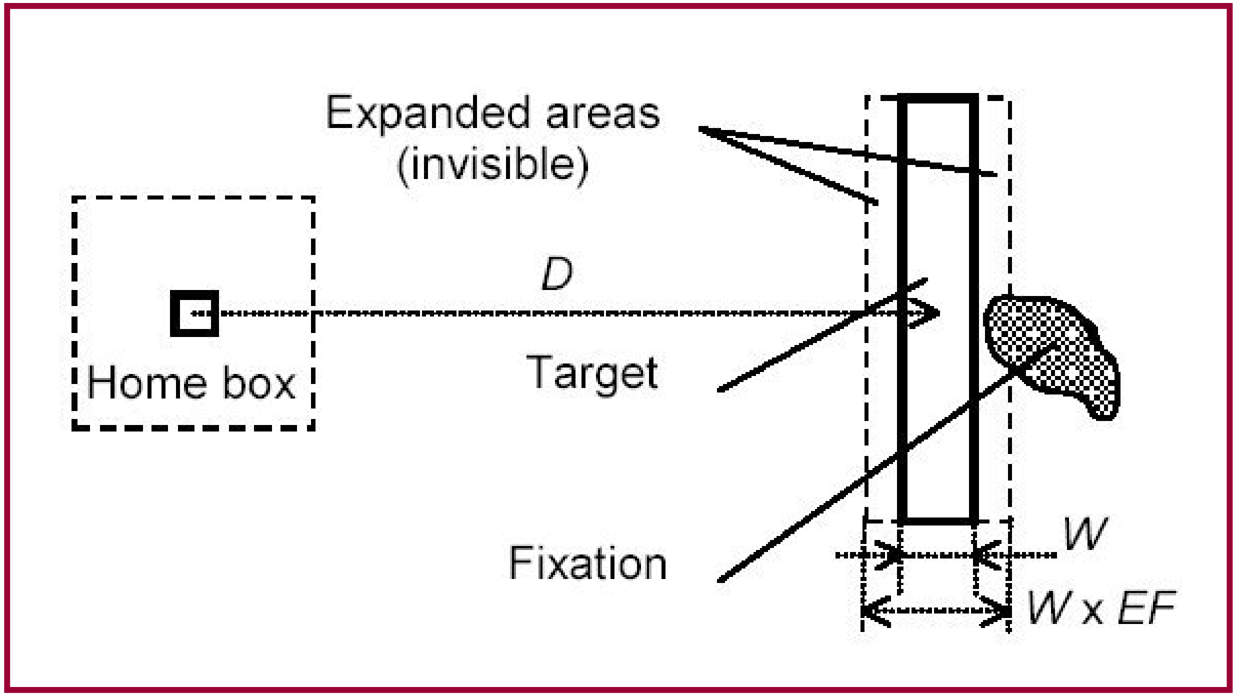
- Target acquisition complicated by
  - Fovea's "region of uncertainty"
  - Eye jitter and drift
  - Identifying a fixation from raw data
  - No natural selection method for eye tracking
- Selection methods
  - Dwell time (250 ms to 1000 ms)
  - Separate key press
  - Blink, wink, frown, etc.
- E.g., "smart" target acquisition techniques

Nearest Neighbor Selection[1]



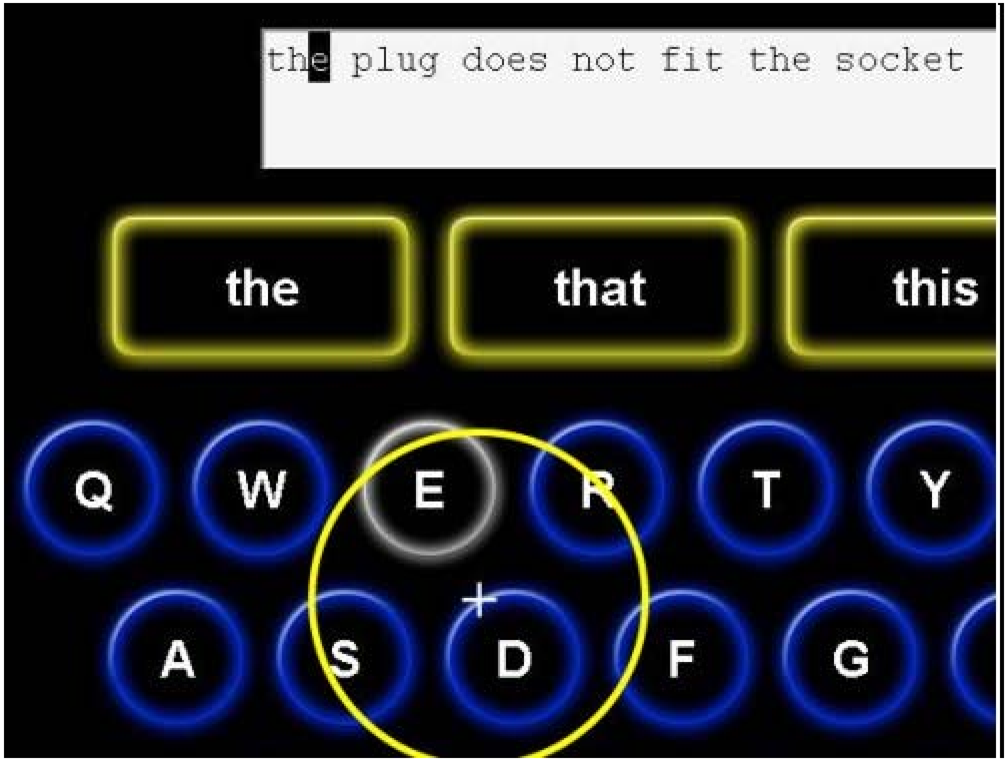
[1] Sibert, L. E., & Jacob, R. J. K. (2000). Evaluation of eye gaze interaction. *Proceedings of CHI 2000*, 281-288. New York: ACM.

Grab And Hold Algorithm[1]



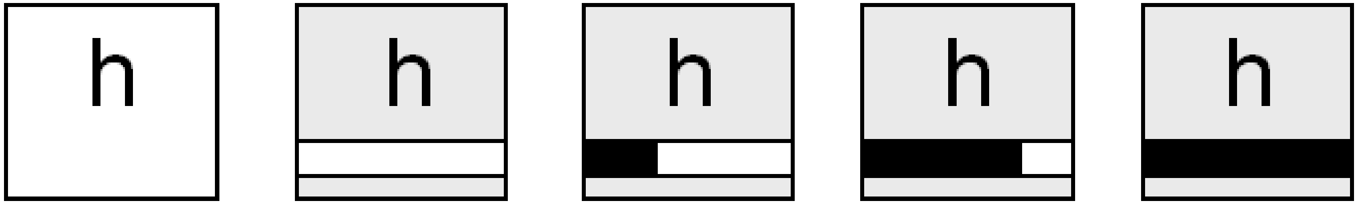
[1] Miniotas, D., Špakov, O., & MacKenzie, I. S. (2004). Eye gaze interaction with expanding targets. *Ext Abstracts CHI 2004*, 1255-1258. New York: ACM.

Next-letter Prediction[1]



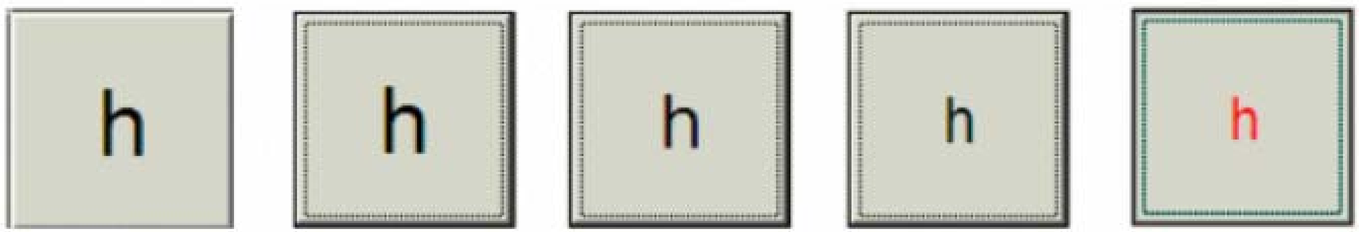
[1] MacKenzie, I. S., & Zhang, X. (2008). Eye typing using word and letter prediction and a fixation algorithm. *Proceedings of ETRA 2008*, 55-58. New York: ACM.

Dwell-time Progress Indicators[1]



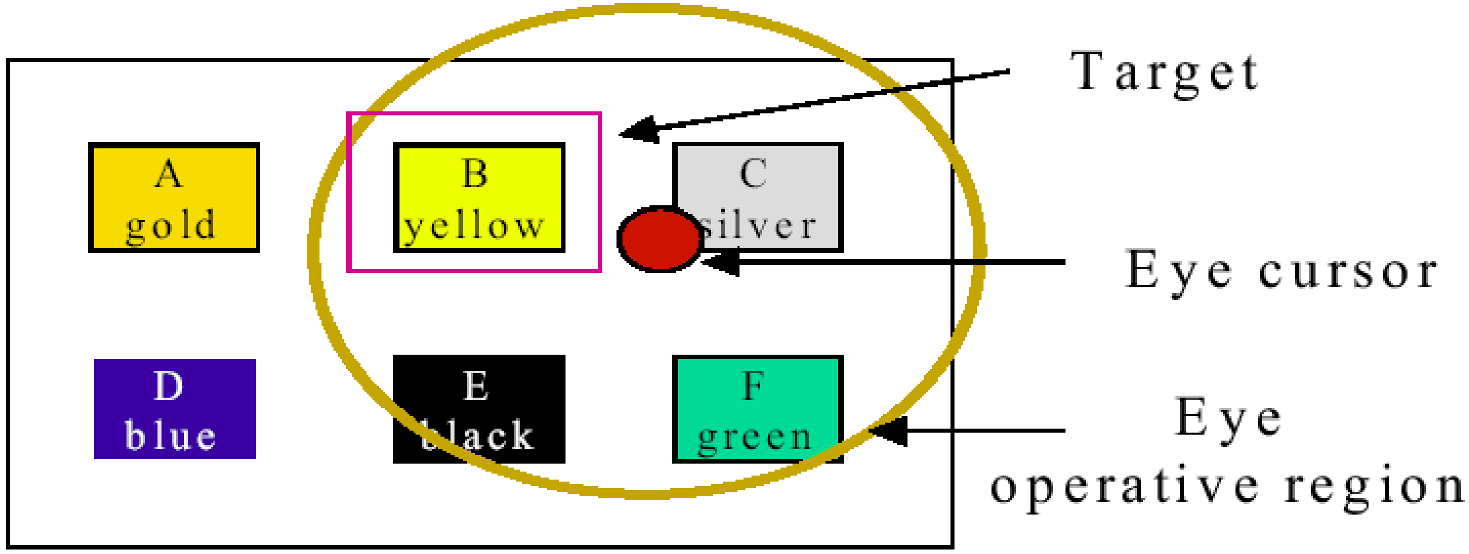
[1] Hansen, J. P., Hansen, D. W., & Johansen, A. S. (2001). Bringing gaze-based interaction back to basics. *Proceedings of HCII 2001*, 325-328. Mahwah, NJ: Erlbaum.

Shrinking Letter Progress Indicator[1]



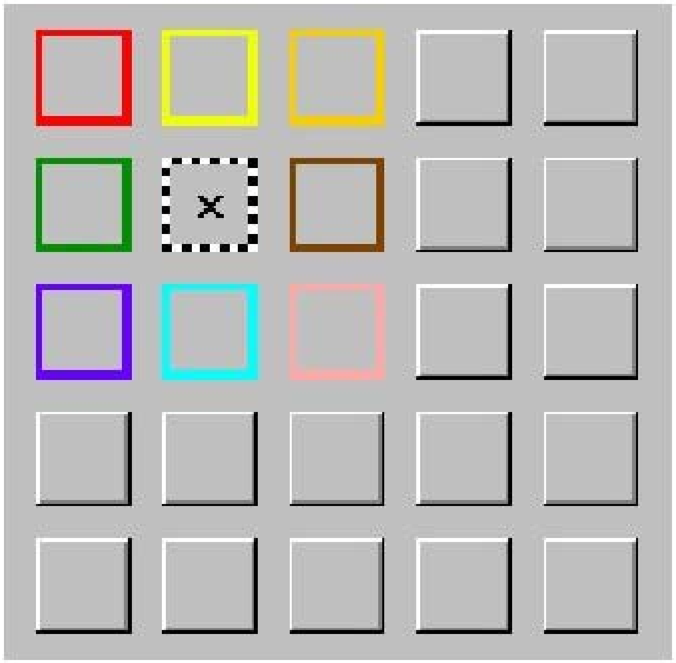
[1] Majaranta, P., MacKenzie, I. S., Aula, A., & Räiha, K.-J. (2003). Auditory and visual feedback during eye typing. *Ext Abstracts of CHI 2003*, 766-767. New York: ACM.

Speech-assisted Selection[1]



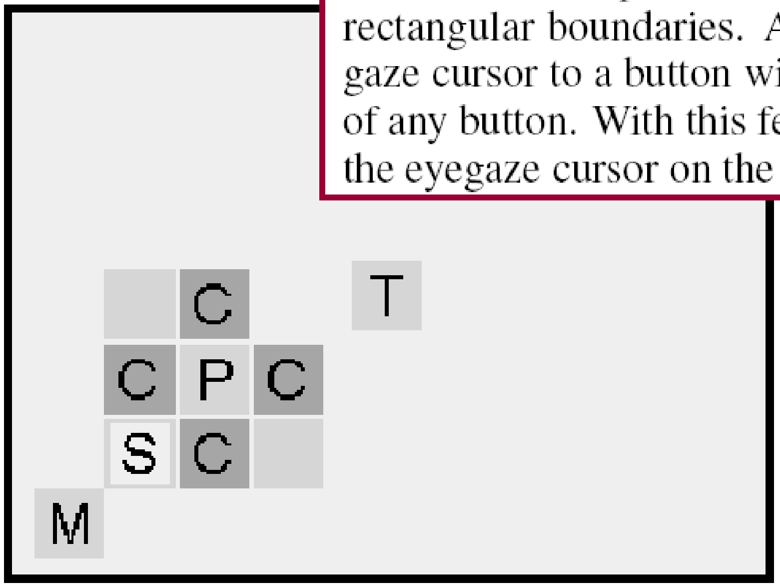
[1] Zhang, Q., Imamiya, A., Go, K., & Mao, X. (2004). Resolving ambiguities of a gaze and speech interface, *Proceedings of ETRA 2004* (pp. 85-92): New York: ACM.

Speech-assisted Selection[1]



[1] Miniotas, D., Spakov, O., & MacKenzie, I. S. (2006). Speech-augmented eye gaze interaction with small closely-spaced targets. *Proceedings of ETRA 2006*, 67-72. New York: ACM.

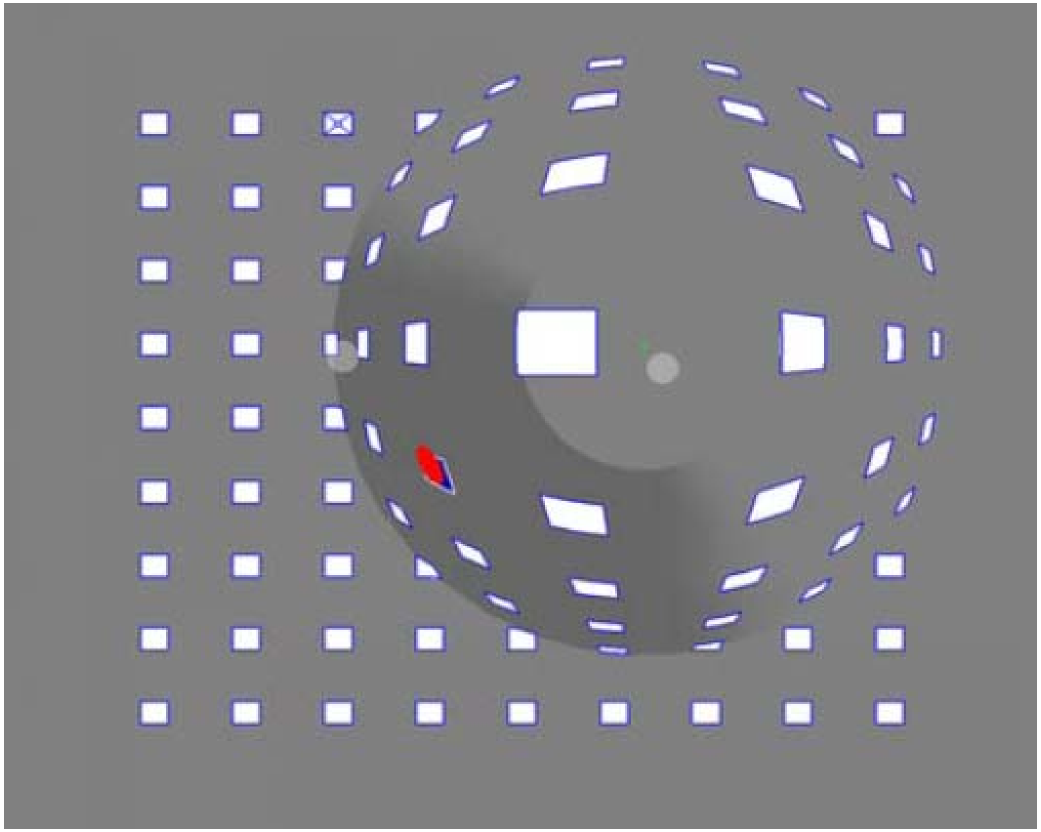
Snap-on Selection[1]



To improve the speed from the pilot, fixations are now registered if at least 6 of the previous 10 eyegaze samples fall within a button's rectangular boundaries. A new "snap-on" function forces the eyegaze cursor to a button within a radius of 85 pixels from the centre of any button. With this feature, users require far less effort to keep the eyegaze cursor on the desired menu item.

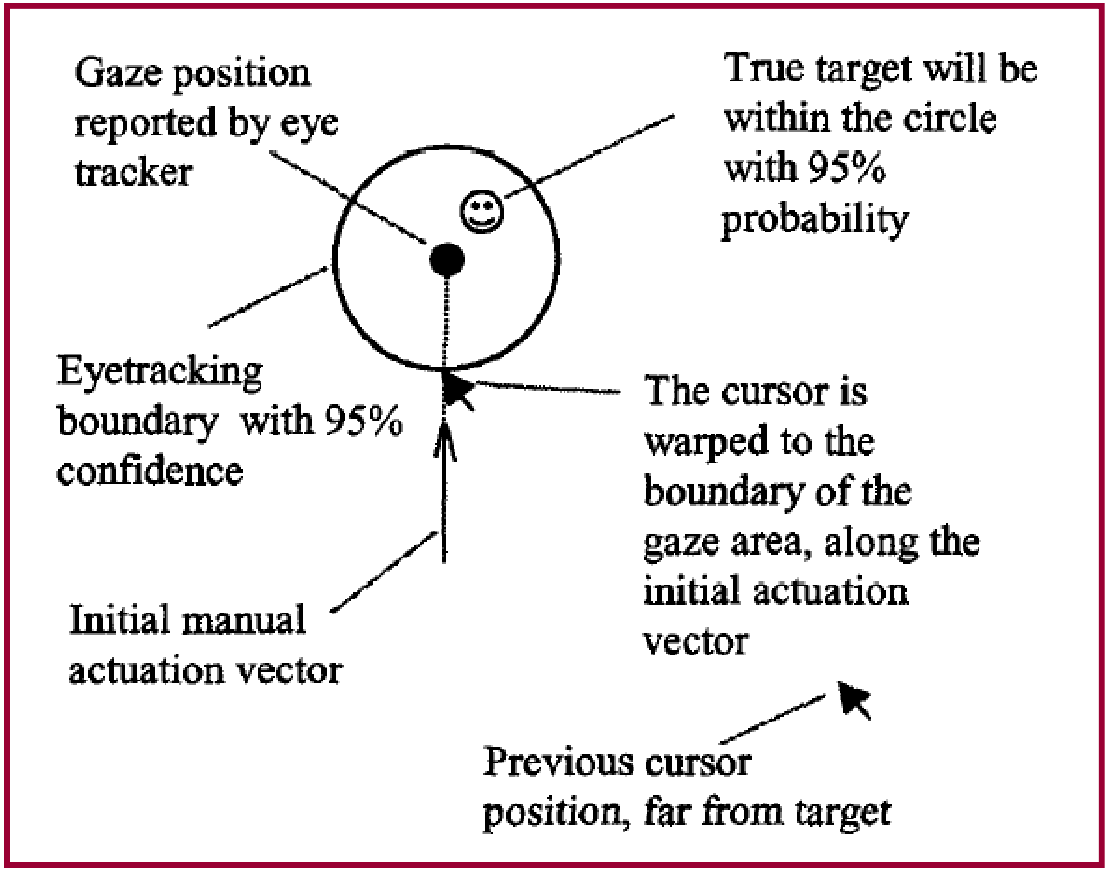
[1] Tien, G., & Atkins, M. S. (2008). Improving hands-free menu selection using eye gaze glances and fixations. *Proceedings of ETRA 2008*, 47-50. New York: ACM.

Fisheye Lens Selection[1]



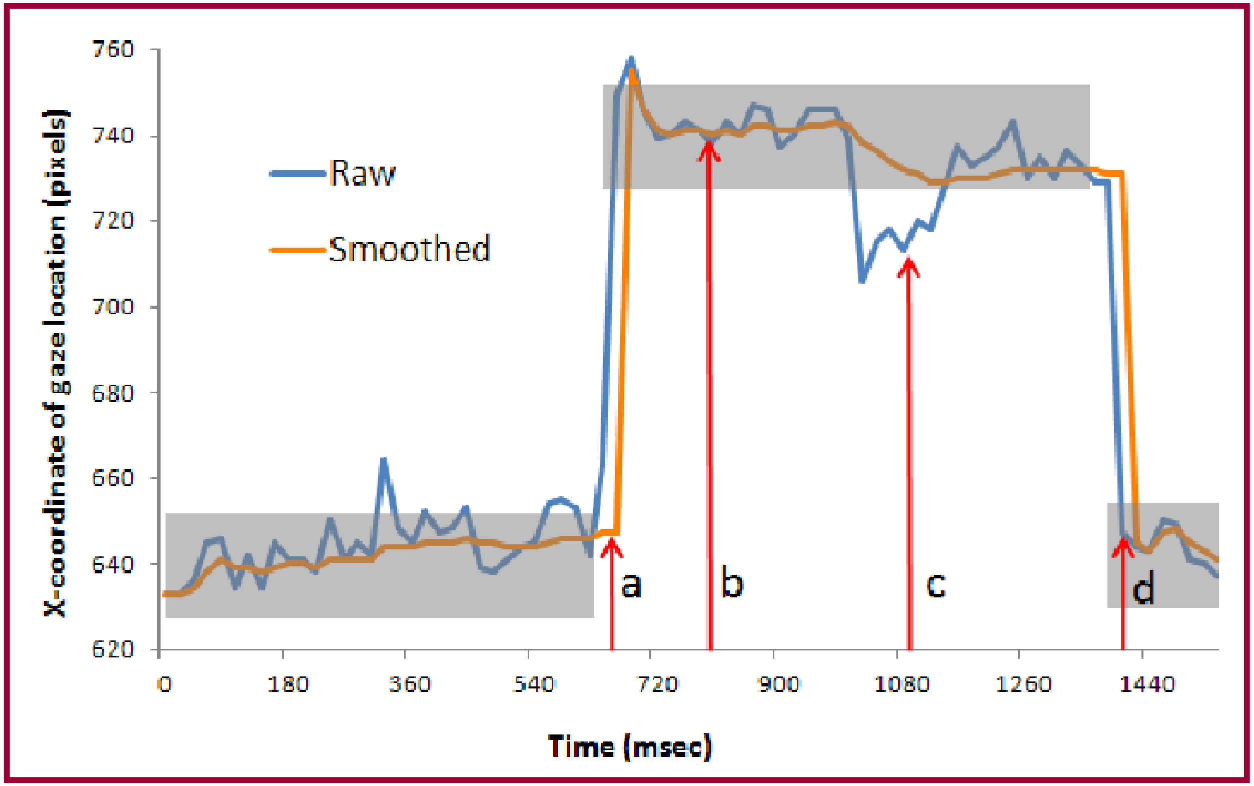
[1] Ashmore, M., Duchowski, A. T., & Shoemaker, G. (2005). Efficient eye pointing with a fisheye lens. *Proceedings of Graphics Interface 2005*, 203-210. Toronto: Canadian Information Processing Society.

Cursor Warping[1]



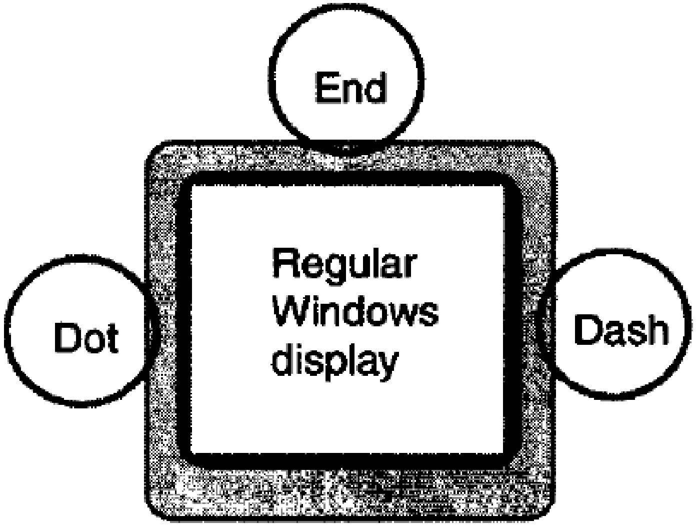
[1] Zhai, S., Morimoto, C., & Ihde, S. (1999). Manual gaze input cascaded (MAGIC) pointing. *Proceedings of CHI '99*, 248-253. New York: ACM.

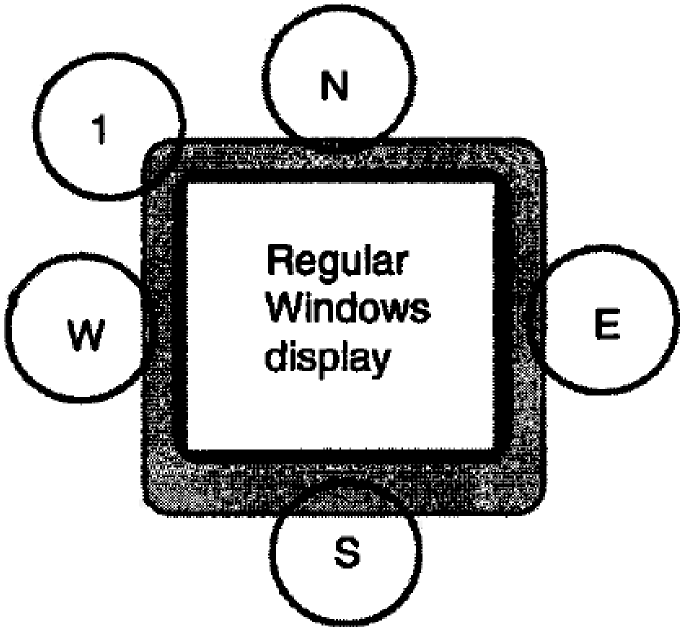
Early-raw-smoothed-late Selection[1]



[1] Kumar, M., Klingner, J., Winograd, T., & Paepcke, A. (2008). Improving the accuracy of gaze input for interaction. *Proceedings of ETRA 2008*, 65-68. New York: ACM.

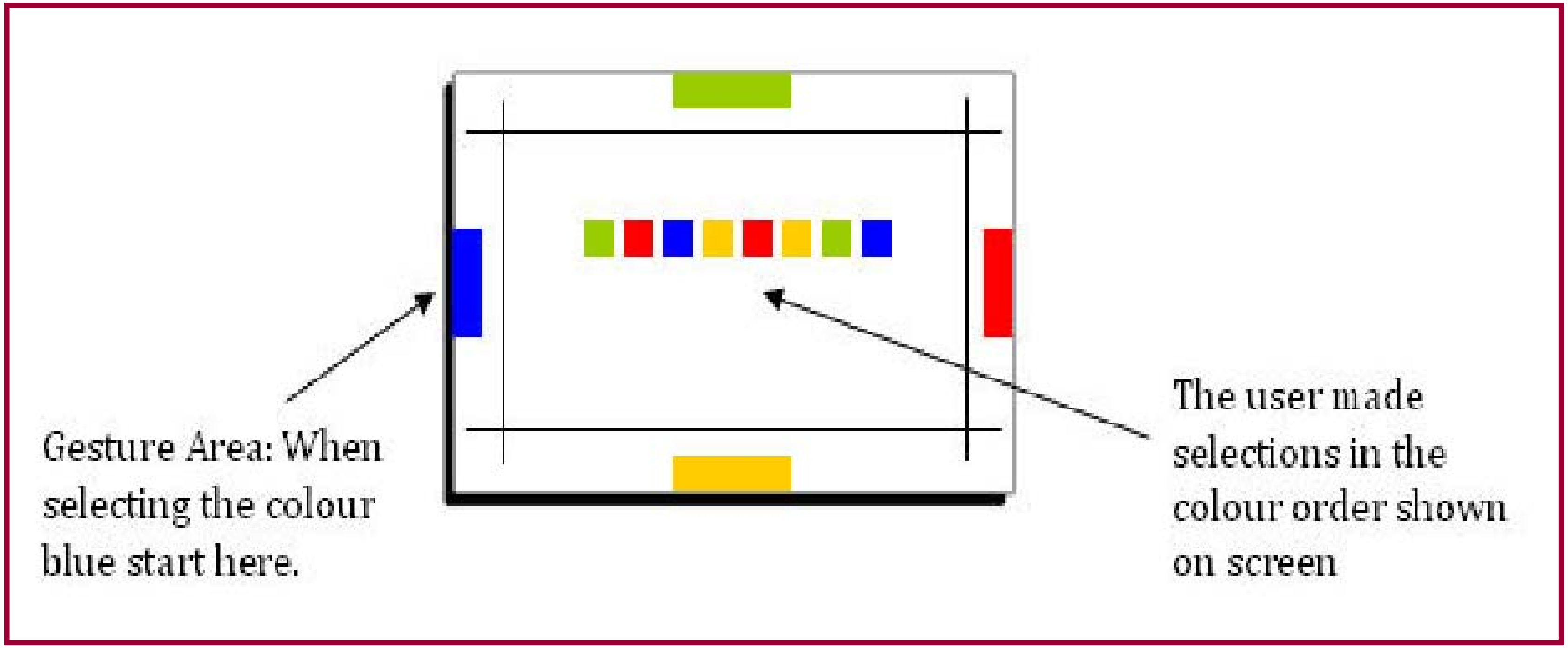
Off-screen Targets[1]





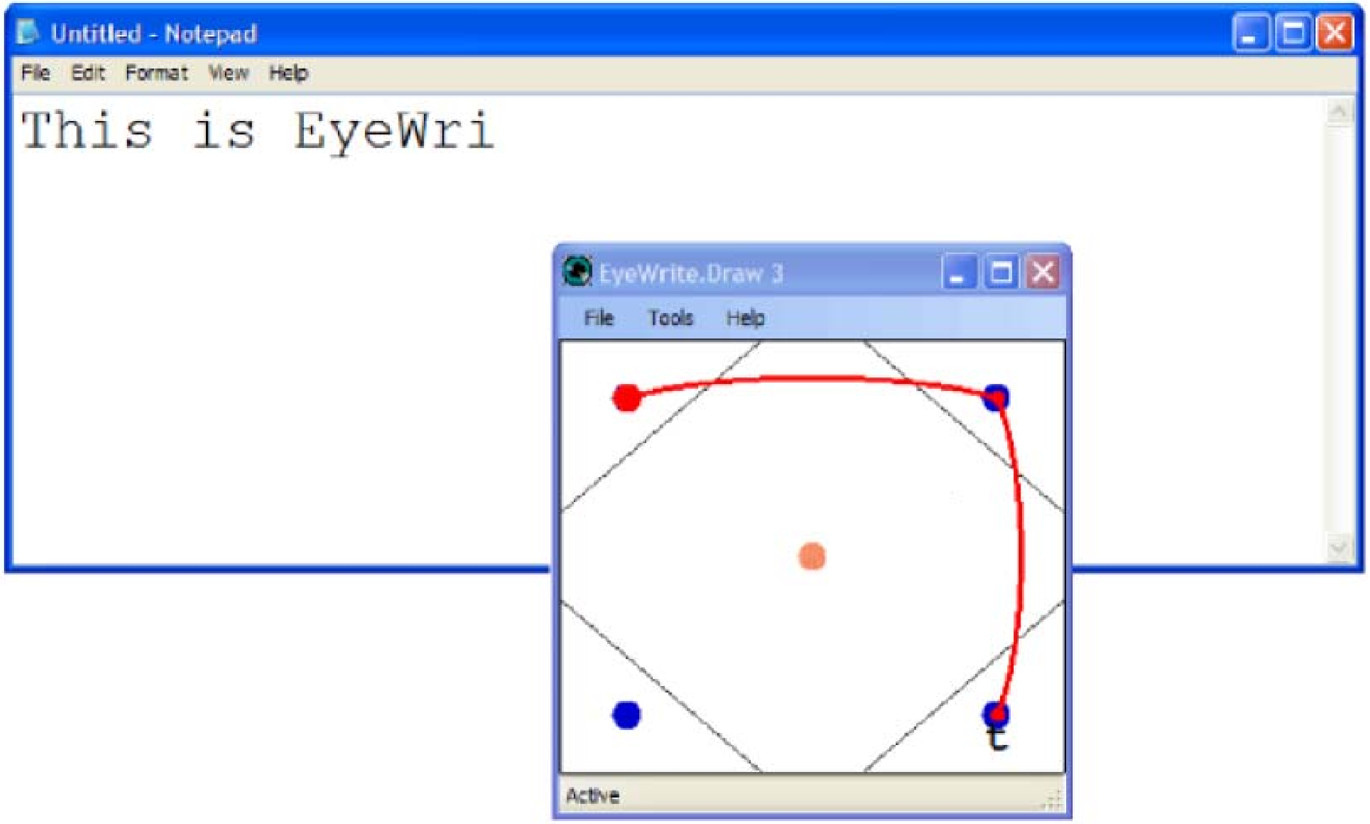
[1] Isokoski, P. (2000). Text input methods for eye trackers using off-screen targets. *Proceedings of ETRA 2000*, 15-21. New York: ACM.

Eye Gestures (off-screen targets)[1]



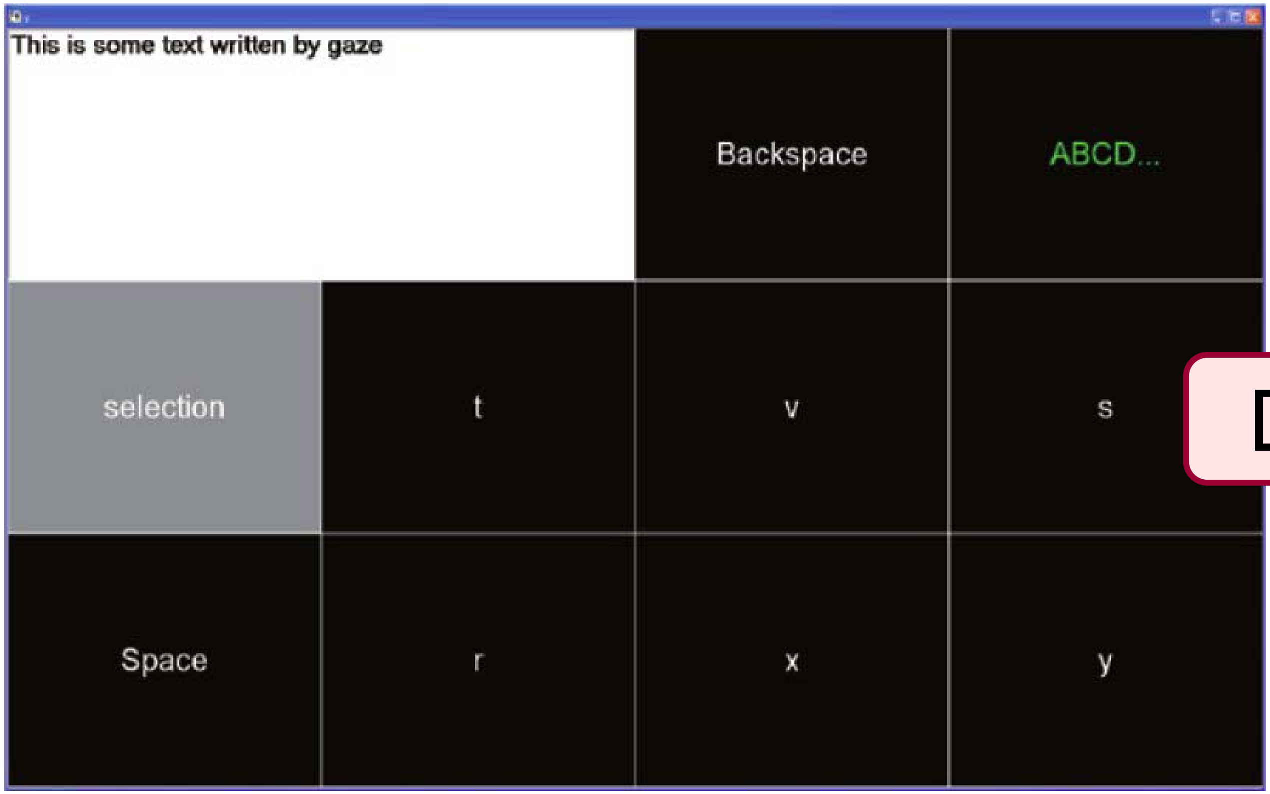
[1] Mollenbach, E., Hansen, J. P., Lillholm, M., & Gale, A. G. (2009). Single stroke gaze gestures. *Ext Abstracts of CHI 2009*, 4555-4560. New York: ACM.

Eye Gestures[1]



[1] Wobbrock, J. O., Rubinstein, J., Sawyer, M. W., & Duchowski, A. T. (2008). Longitudinal evaluation of discrete consecutive gaze gestures for text entry. *Proceedings of ETRA 2008*, 11-18, 281. New York: ACM.

Big Targets[1]



Demo

[1] Hansen, J. P., Johansen, A. S., Hansen, D. W., Itoh, K., & Mashino, S. (2003). Command without a click: Dwell time typing by mouse and gaze selection. *Proceedings of INTERACT 2003*, 121-128. Berlin: Springer.

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SKIP

Focus on the Interaction

- Eye tracking research tends to focus on the technology (hardware, software, algorithms)
- Focus on the interaction
- With eye tracking, easier said than done
- Eye tracking technology is *finicky* (perhaps you have a better word)
- Remember the *human-computer interface* (5th slide)

Evaluation Paradigm

- Experimental in nature
- Follow "the Scientific Method"
  - Human participants
  - Independent variables (factors and levels)
  - Dependent variables (measure behaviours)
  - Counterbalancing
  - Hypothesis testing (analysis of variance)
  - Etc.

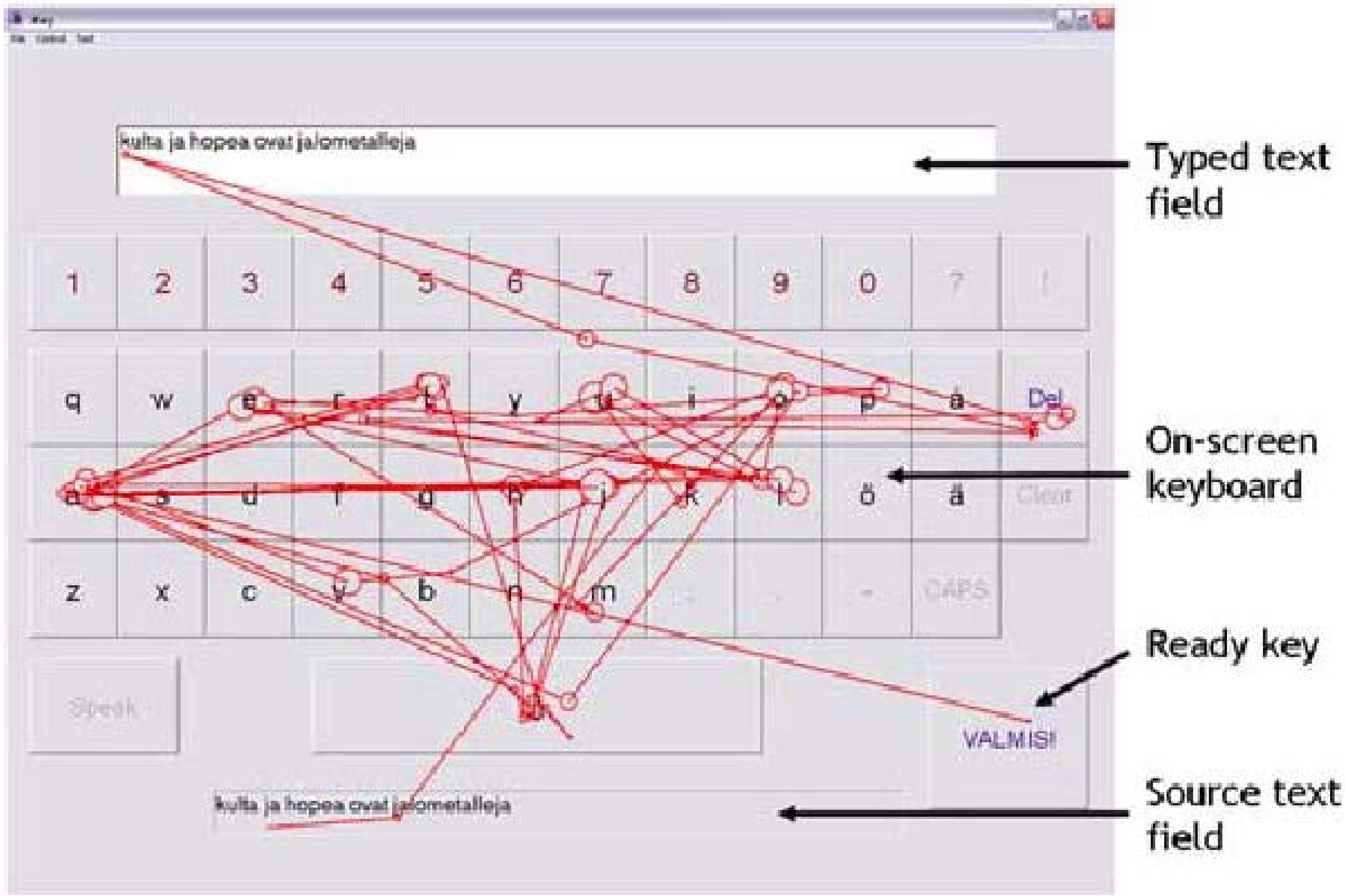
Independent Variables (eye tracking)

Independent Variable	Study	Description
Cursor redressment method	[11]	Comparison of four methods to improve the stability of the eye cursor by counteracting eye jitter. The methods were force field, speed reduction, warping to target center, and none.
Prediction mode	[10]	Comparison of letter prediction and word prediction in eye typing using a soft keyboard.
Algorithm	[9]	Comparison of two settings of an algorithm to improve target selection by warping the eye cursor's area to encompass the target
Fisheye mode	[1]	Comparison of four fisheye techniques to improve target selection. The techniques were none, always on, and appearing only after fixation begins (with and without a grab-and-hold algorithm).
Typing system	[4]	Comparison of three eye-typing systems for Japanese text entry. The systems were *Dasher*, and two variants of *GazeTalk* (positioning the text window either at the top-left or centre of the display).
Feedback mode	[5]	Comparison of four feedback modes for keys on a soft keyboard used for text entry. The modes were visual only, click+visual, speech+visual, and speech only.

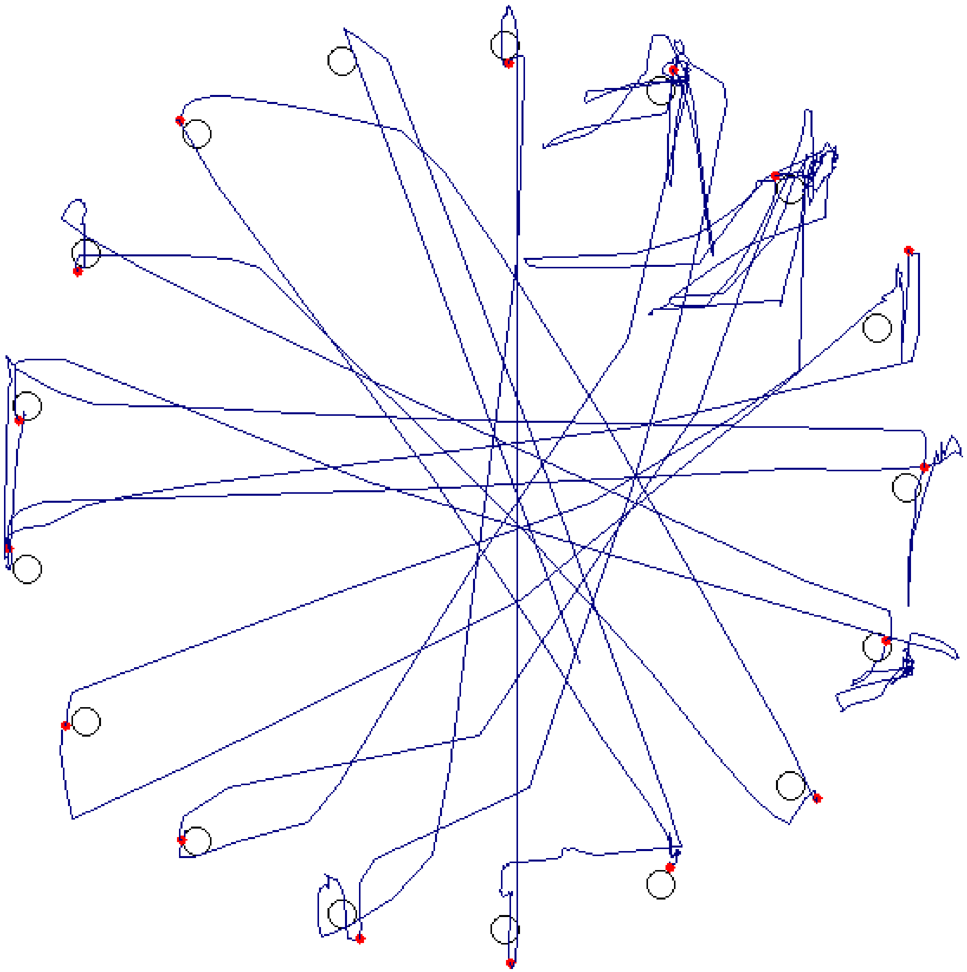
Dependent Variables (eye tracking)

Dependent Variable	Study	Description
Read text events	[5]	During eye typing, the number of times per phrase the point of gaze switches to the typed text field to review the text typed so far.
Over production rate	[3, 4]	During eye typing, the ratio of the actual number of gaze selections to the minimum number needed to construct a given sentence.
Enter target events	[11]	During target selection, the number of times per trial the eye cursor enters the target region.
Saccade rate	[8]	While doing an audio-response task, the number of saccades per second.
Scan paths	[6]	While viewing web pages, the minimum string distance (MSD) between two sequences of scan paths that achieve the same effect.
Off road glances	[7]	In a driving task, the number of times the driver makes an off-road glance (to the radio, mirror, or odometer)

Read Text Events (RTE)



Eye Tracking Path Characteristics



Are there observable, measurable behaviours here – that can be used as dependent variables?

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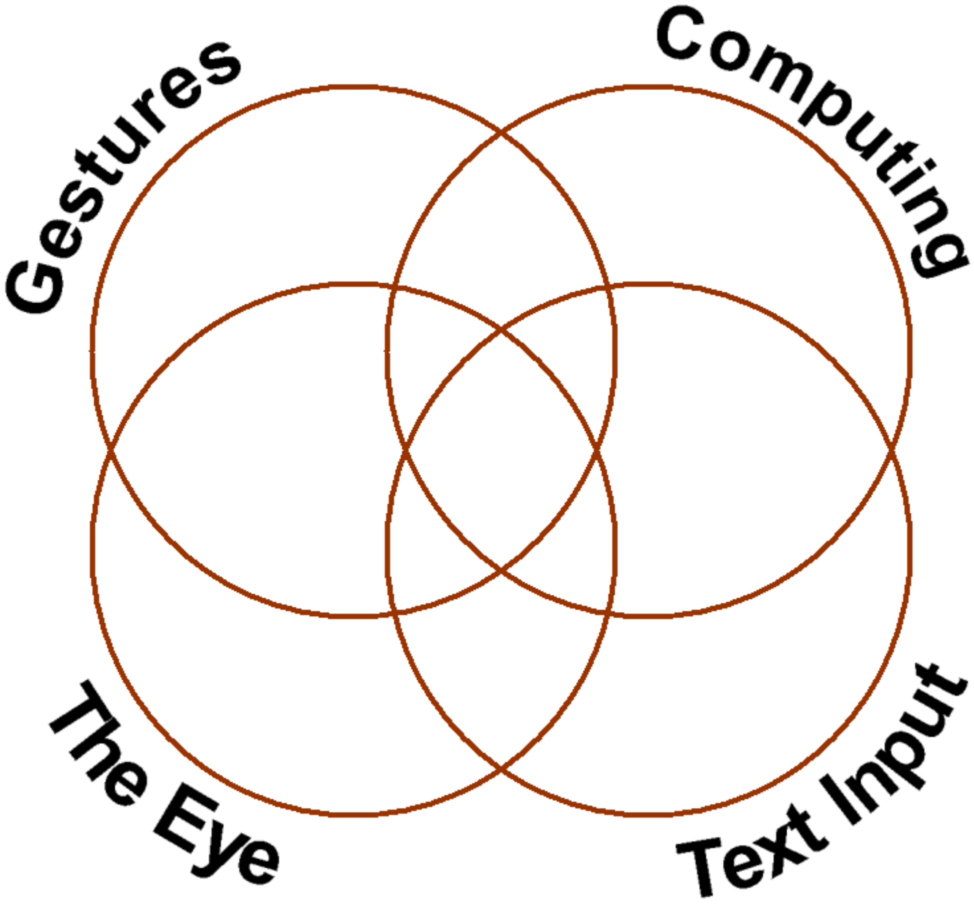
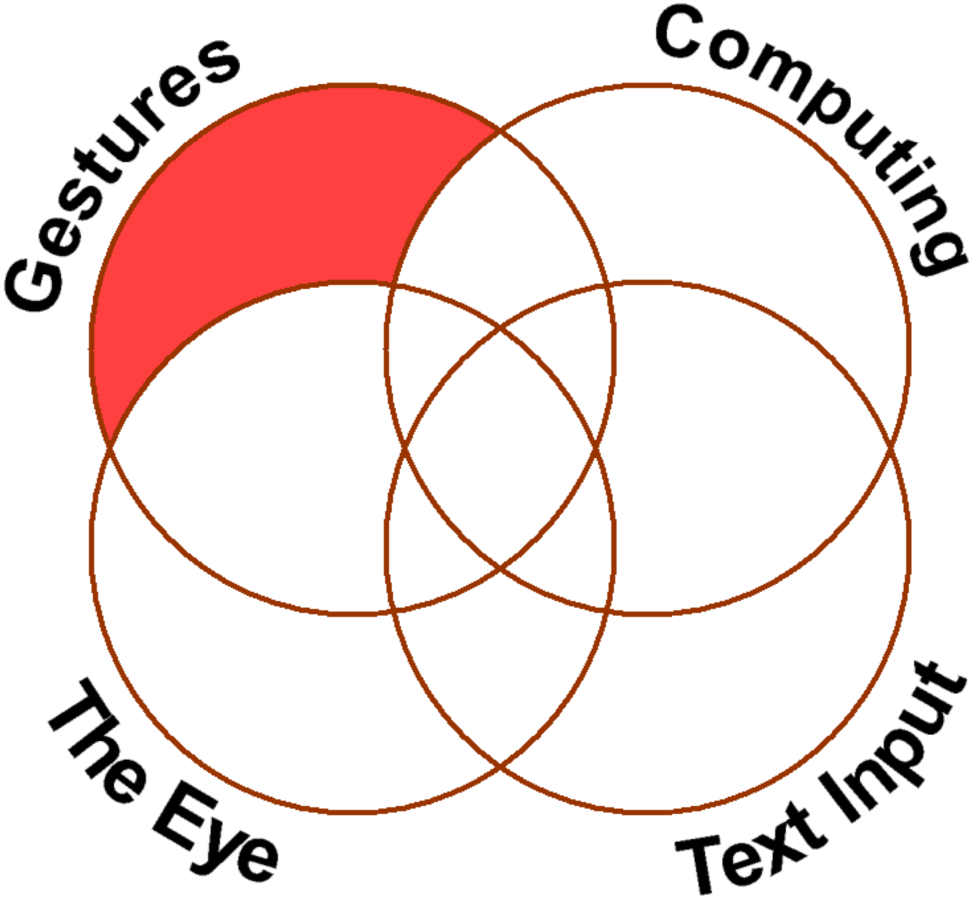
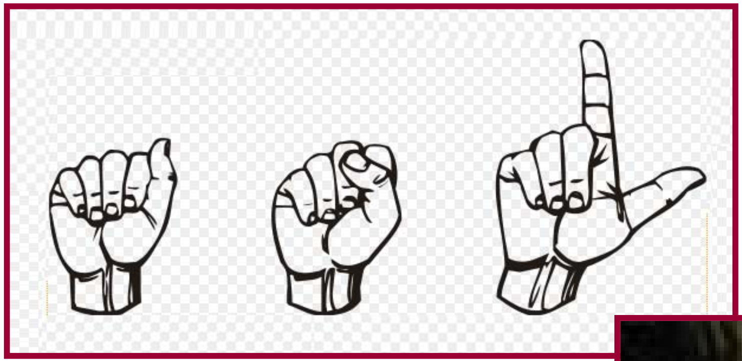
Eye Typing With Gestures



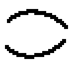
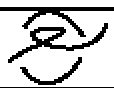
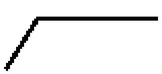
Eye Typing With Gestures



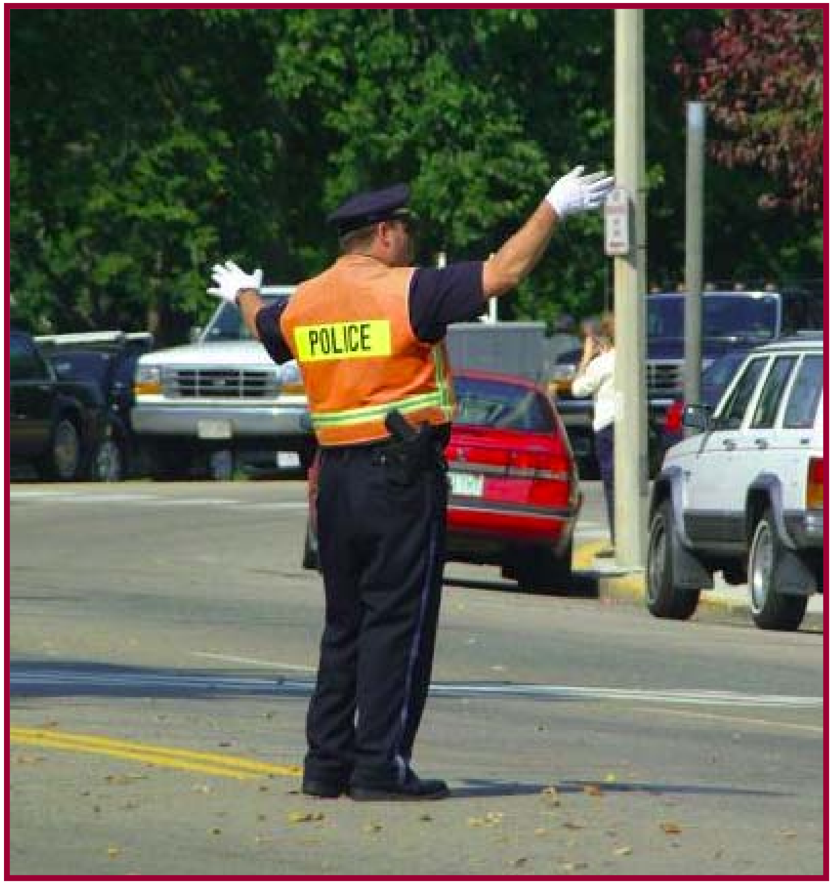
ASL (American Sign Language)



Copy Editing

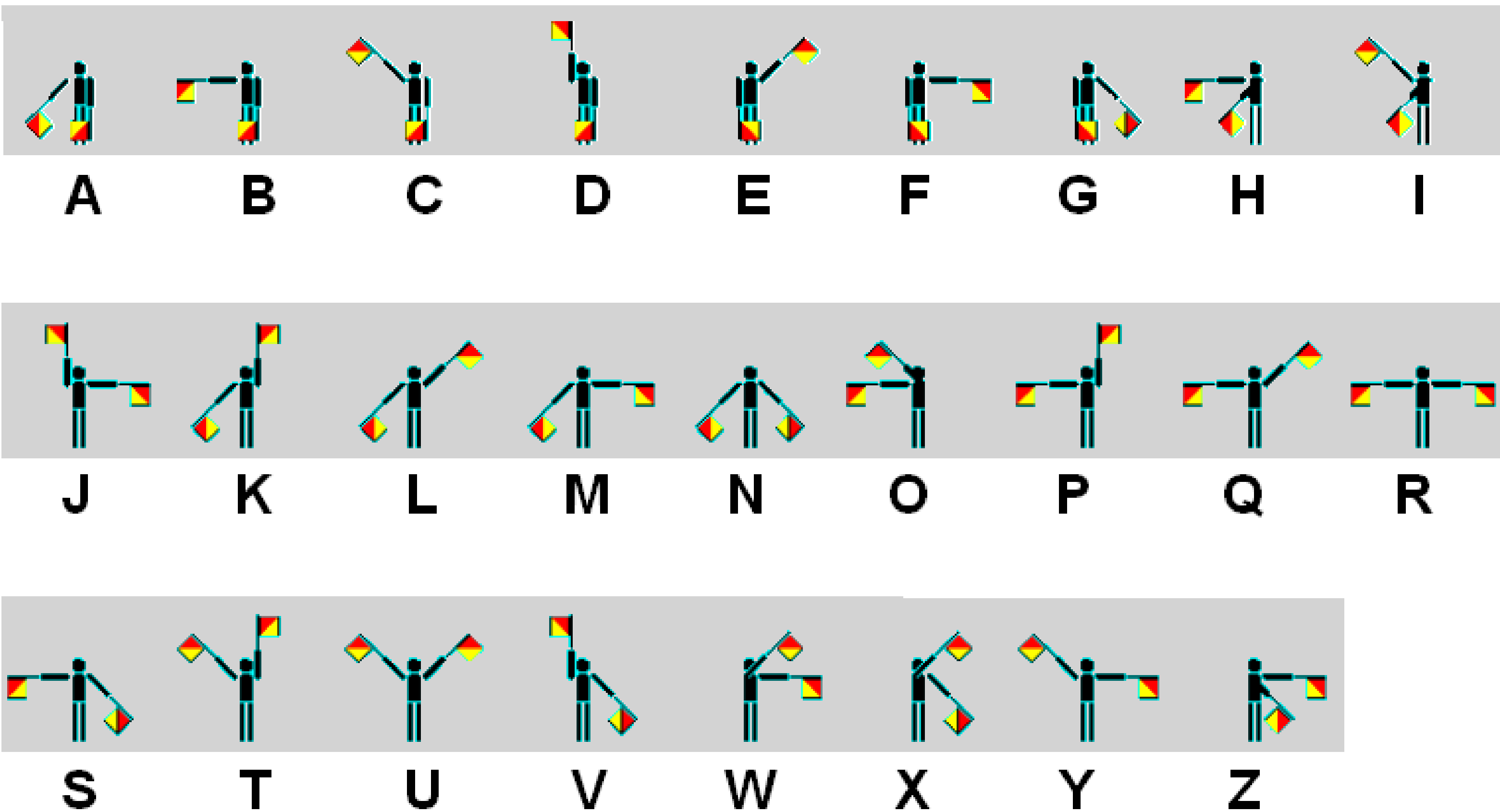
Symbol	Meaning	Example
	Delete	Remove the end fitting.
	Close up	The tolerances are with in the range.
	Delete and Close up	Deltete and close up the gap.
∧	Insert	The box is not inserted correctly.
#	Space	The#procedure is incorrect.
	Transpose	Remove the fitting end.
/ or lc	Lower case	The Engineer and manager agreed.
	Capitalize	A representative of nasa was present.
	Capitalize first letter and lower case remainder	GARRETT PRODUCTS are great.

Traffic Control



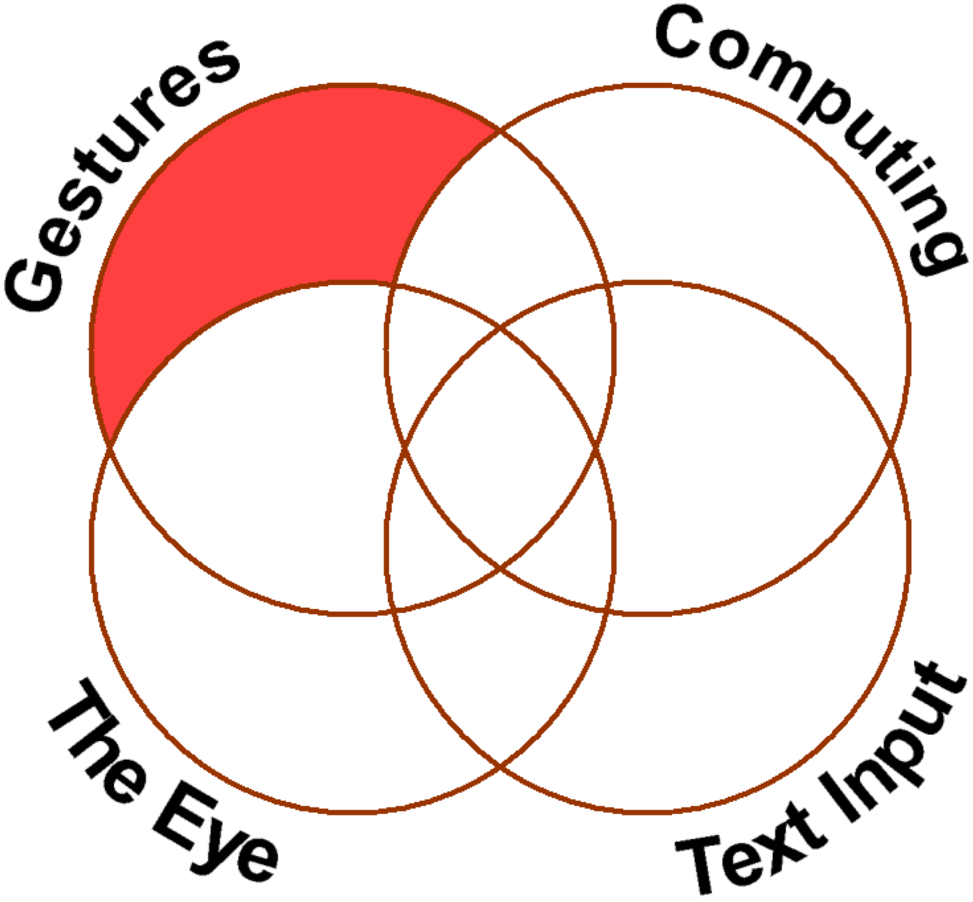
Piazza Venezia

Semaphore Signaling

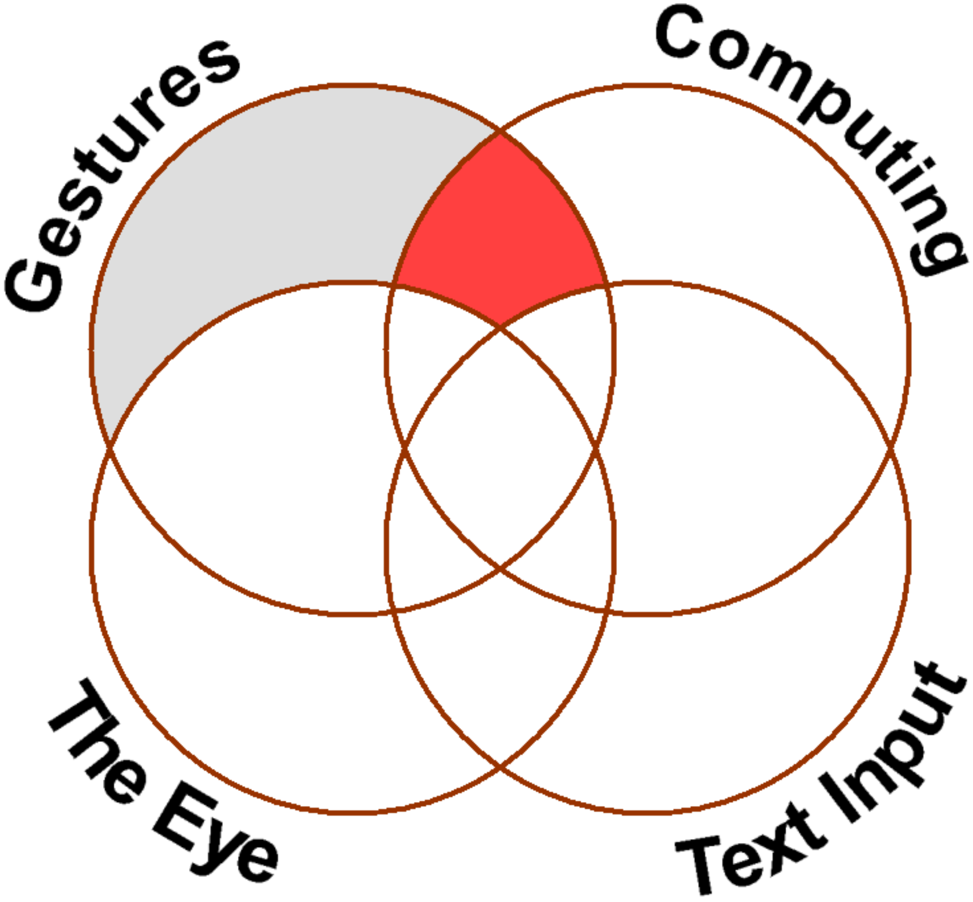


N U J V

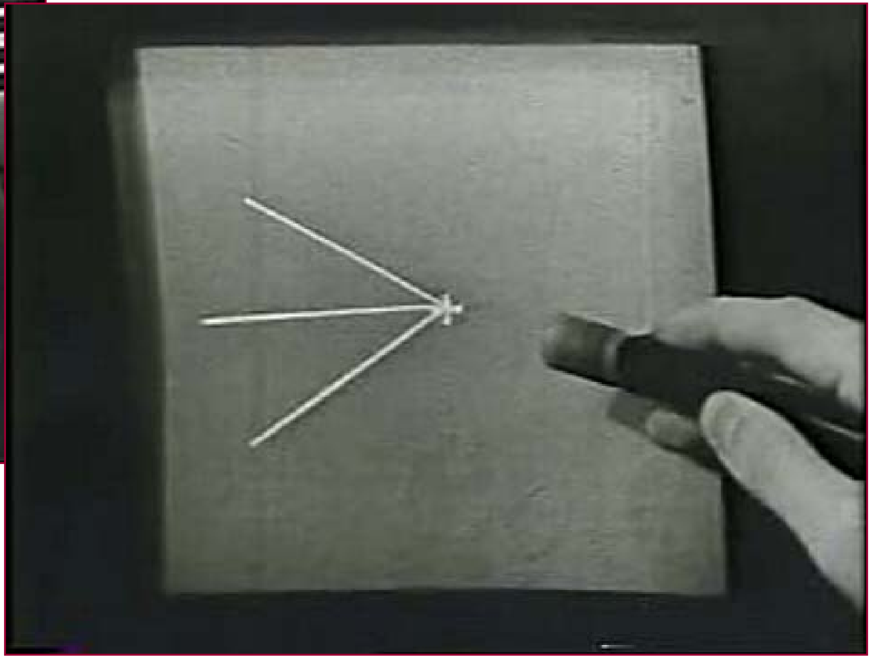
Eye Typing With Gestures



Eye Typing With Gestures

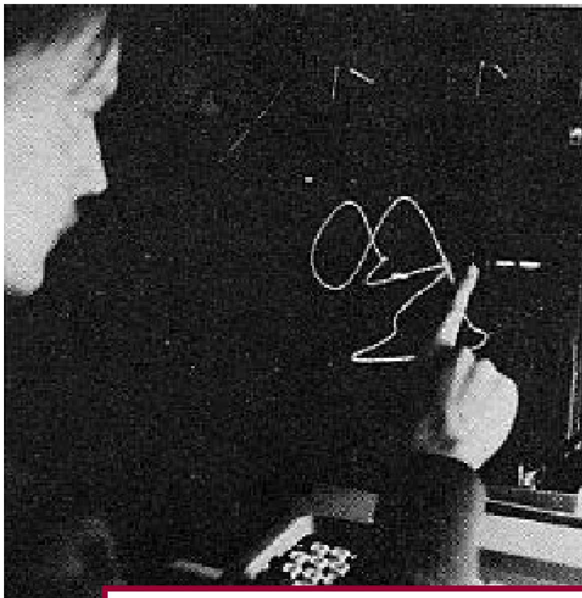


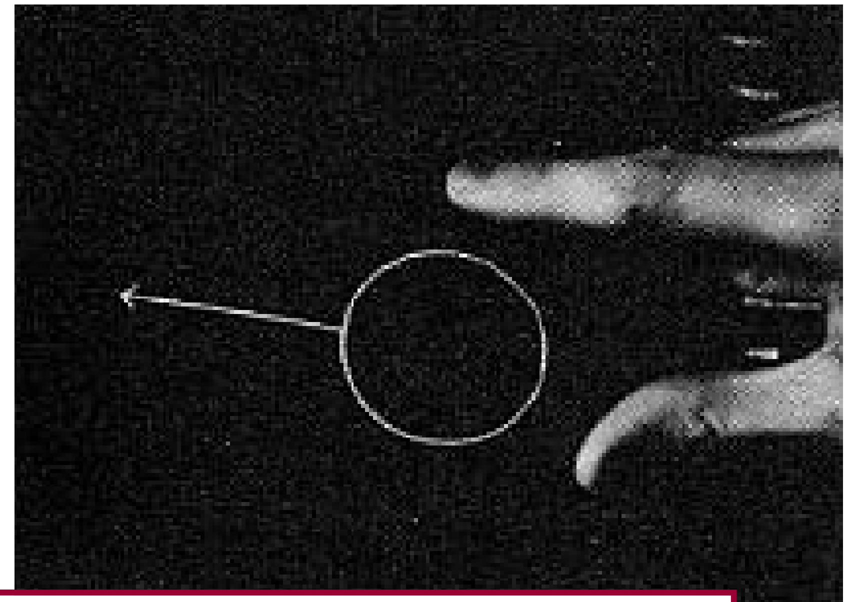
Lightpen on CRT[1]



[1] Sutherland, I. E. (1963). Sketchpad: A man-machine graphical communication system. *Proceedings of the AFIPS Spring Joint Computer Conference*, 329-346. New York: ACM.

Finger(s) on CRT[1]

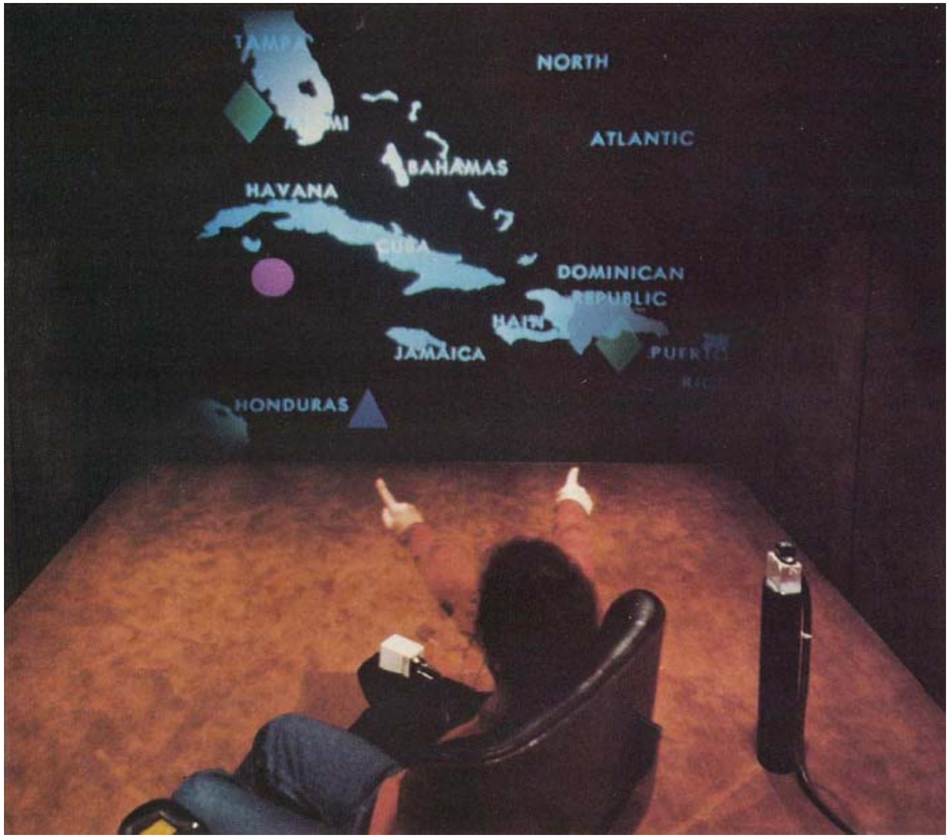




> The excitement generated by TSDs derives directly from their ability to provide a more natural input path to the computer. The umbilical cord attached to the conventional stylus is removed;

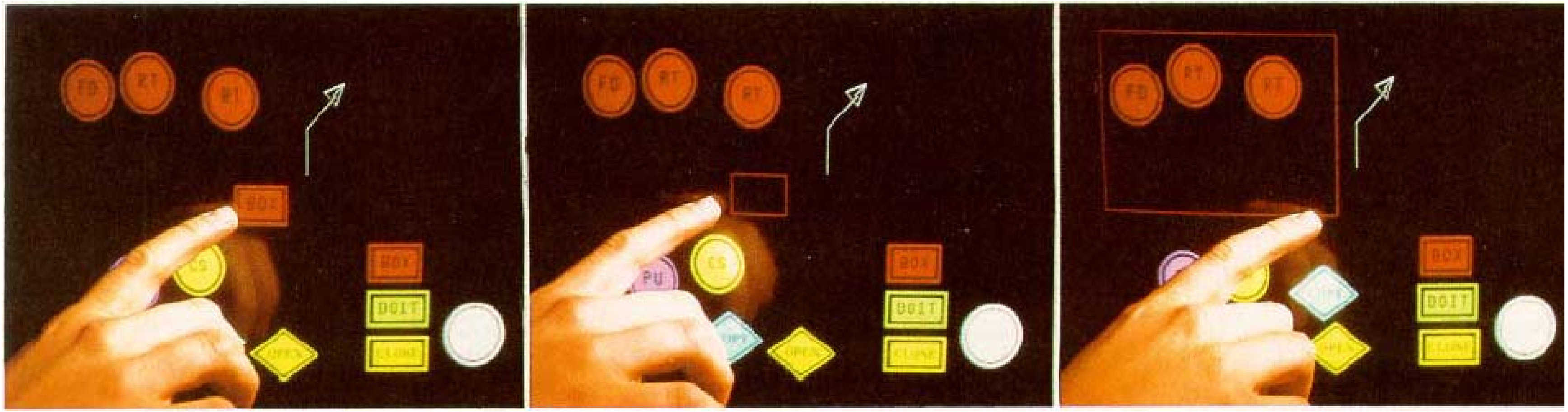
[1] Herot, C. F., & Weinzapfel, G. (1978). One-point touch input of vector information for computer displays. *Proceedings of SIGGRAPH 1978*, 210-216. New York: ACM.

Pointing[1]



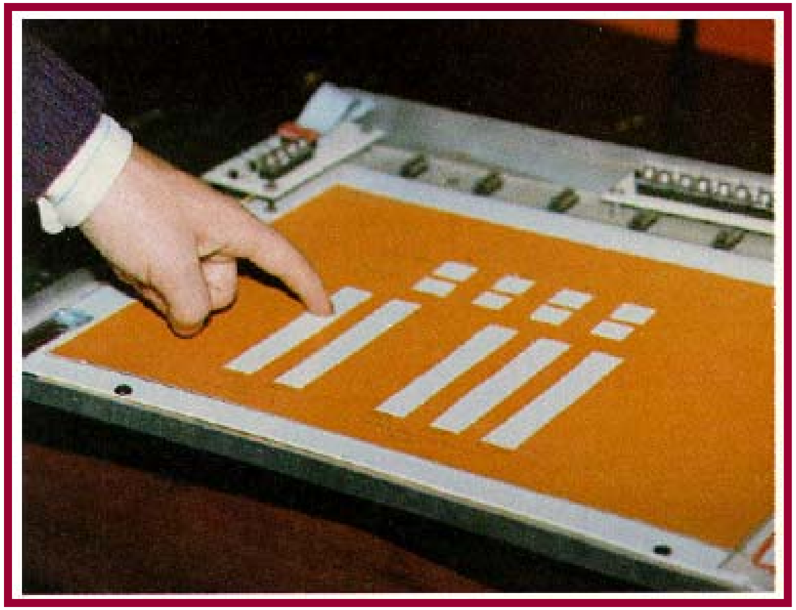
[1] Bolt, R. (1980). Put-that-there: Voice and gesture at the graphics interface. *Computer Graphics, 14*(3), 262-270.

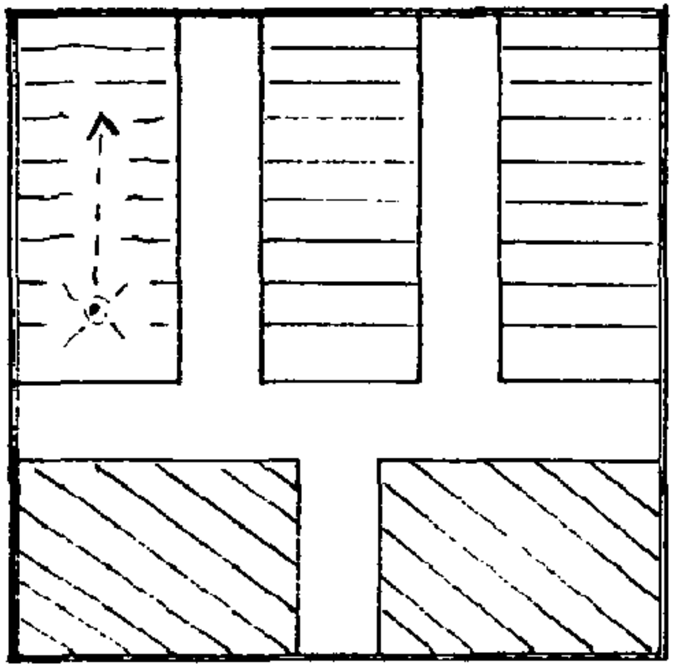
Finger Gestures[1]



[1] Minsky, M. R. (1984). Manipulating simulated objects with real-world gestures using a force and position sensitive screen. *Proceedings of SIGGRAPH 1984*, 195-203. New York: ACM.

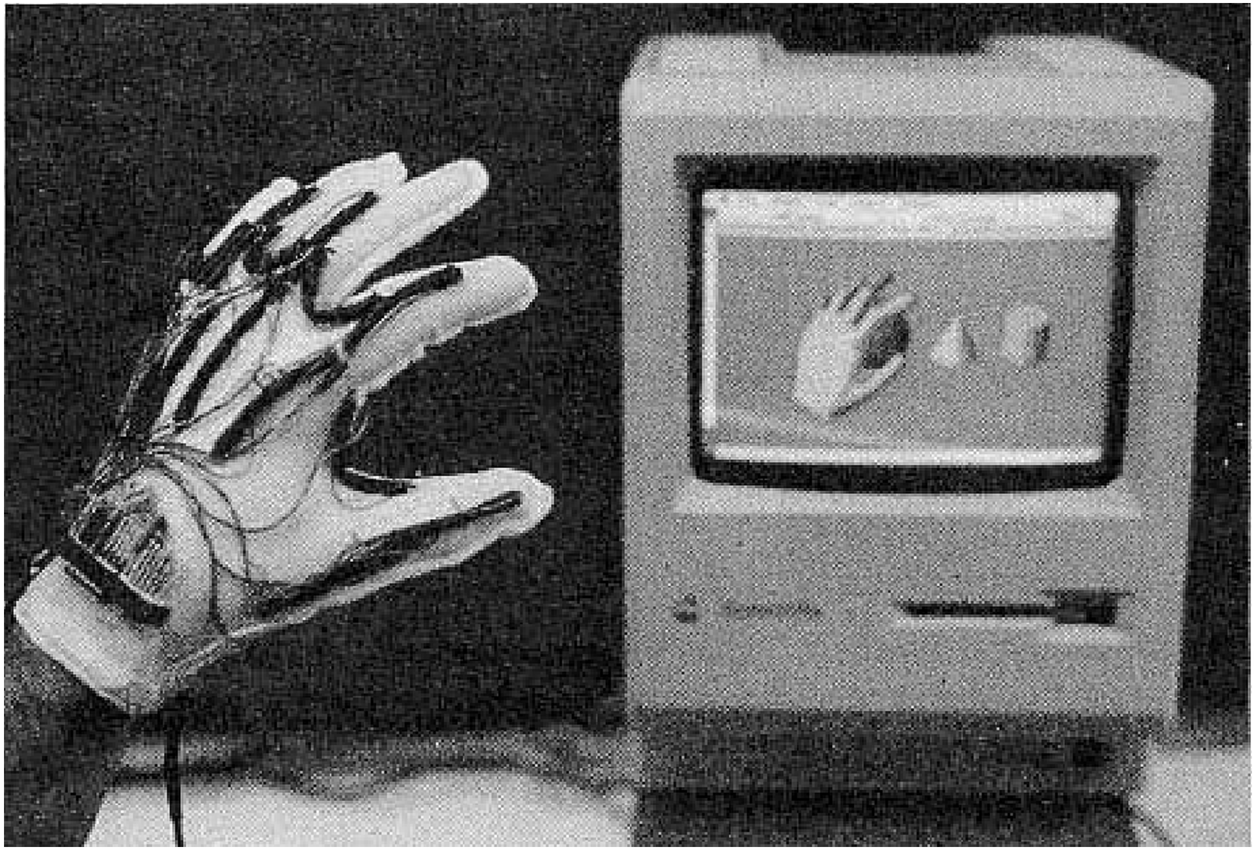
Virtual Devices and Templates[1]





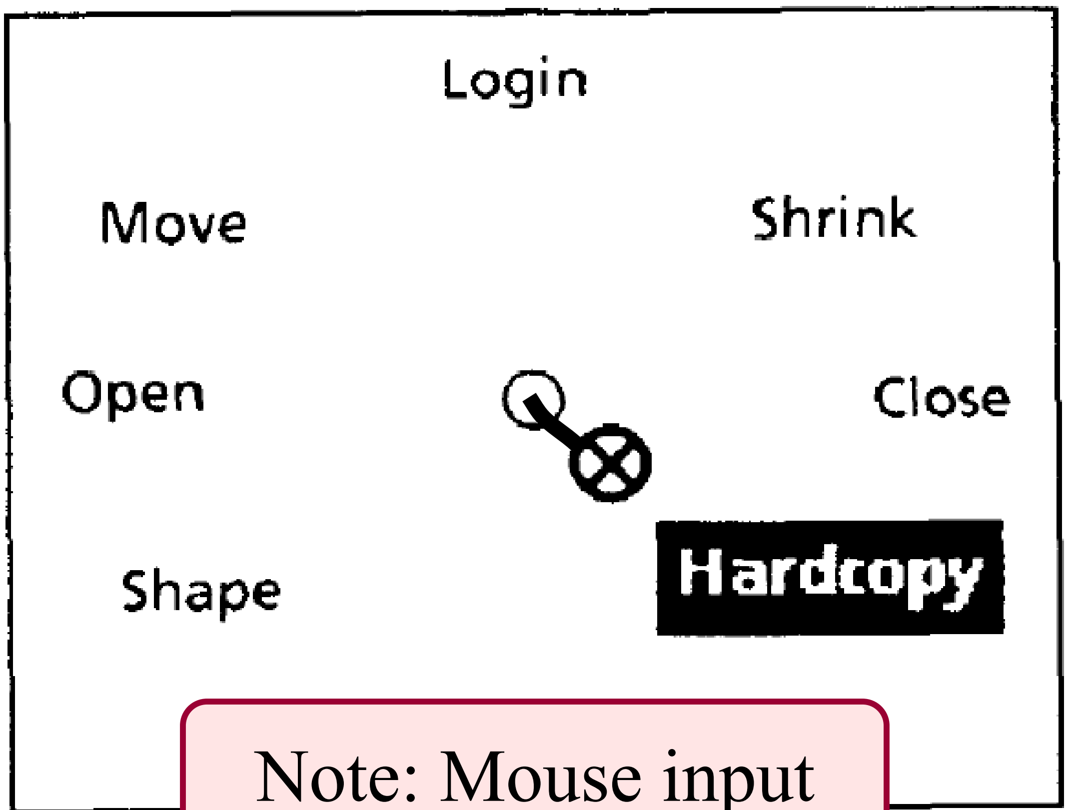
[1] Buxton, W., Hill, R., & Rowley, P. (1985). Issues and techniques in touch-sensitive tablet input. *Proceedings of SIGGRAPH '85*, 215-224. New York: ACM.

Hand Gestures[1]



[1] Zimmerman, T. G., Lanier, J., Blanchard, C., Bryson, S., & Harvill, Y. (1987). A hand gesture interface device. *Proceedings of CHI+GI 1987*, 189-192.

Pie Menus[1]



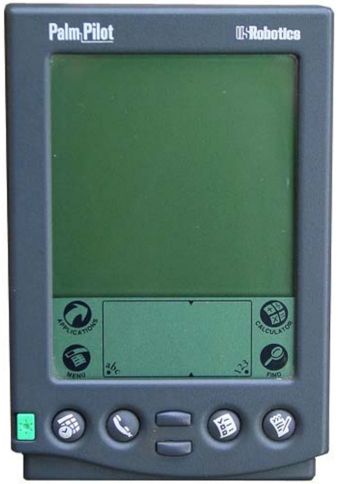
Note: Mouse input

[1] Callahan, J., Hopkins, D., Weiser, M., & Shneiderman, B. (1988). An empirical comparison of pie vs. linear menus. *Proceedings of CHI '88*, 95-100. New York: ACM.

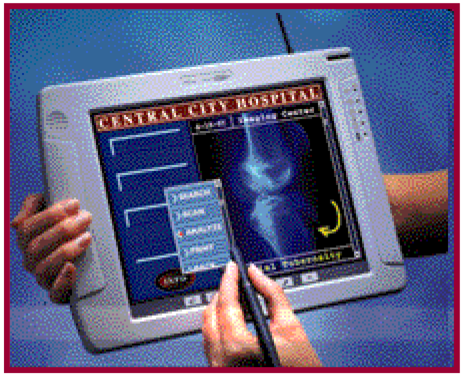
Pen-based Computing (early 1990s)

GRiDPad (Grid Systems)

MessagePad 2100 (Apple)

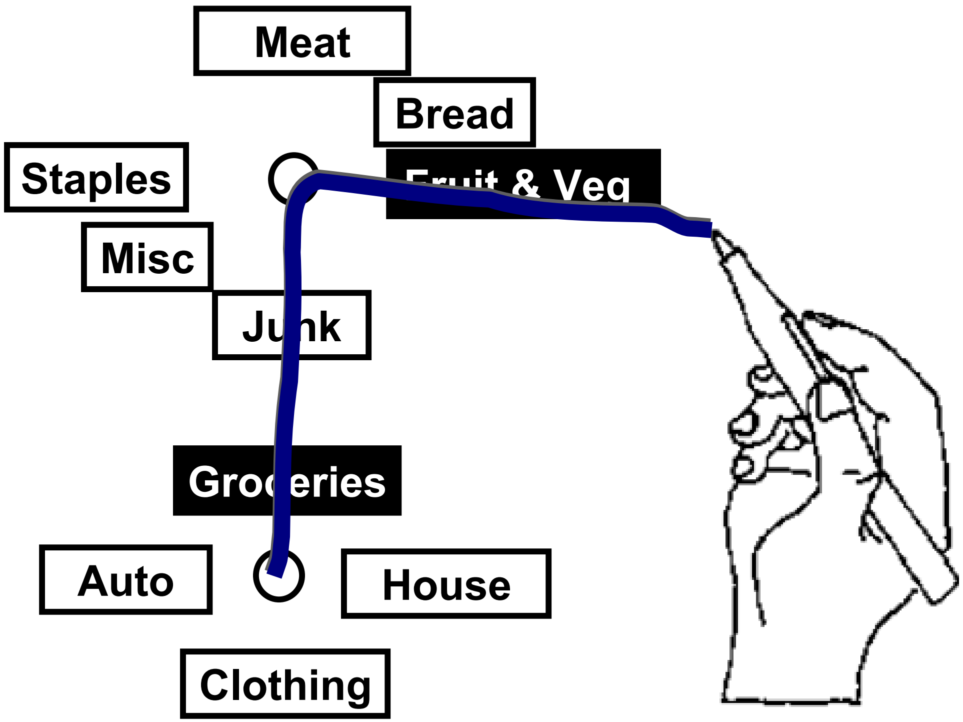


Pilot (Palm)



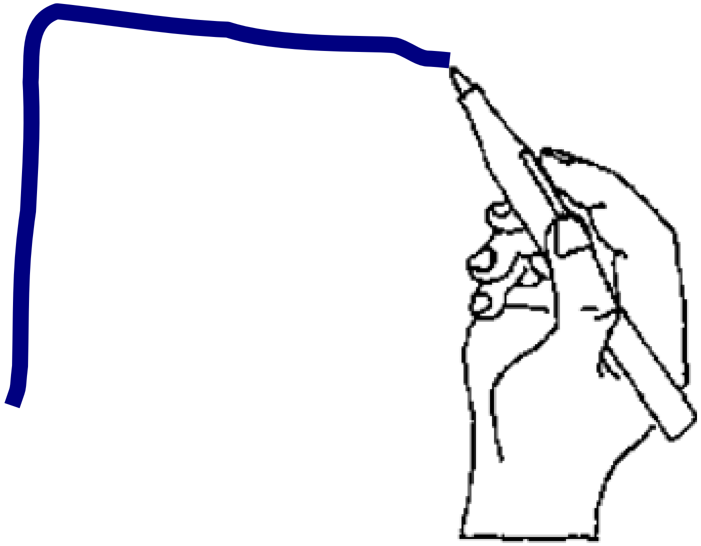
325 Point (Fujitsu)

Marking Menus[1]



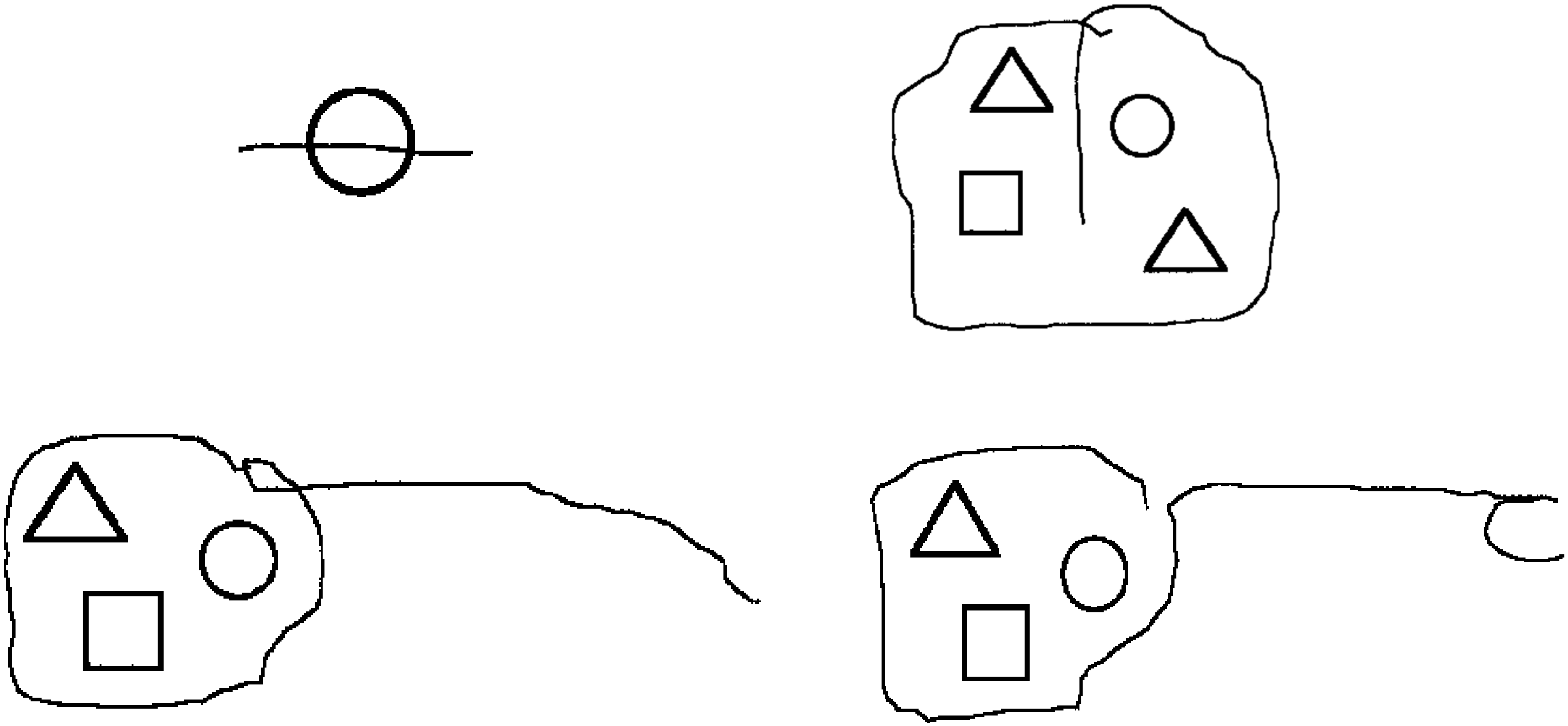
[1] Kurtenbach, G., & Buxton, W. (1993). The limits of expert performance using hierarchic marking menus. *Proceedings of the INTERCHI '93*, 482-487. New York: ACM.

Marking Menus[1]



[1] Kurtenbach, G., & Buxton, W. (1993). The limits of expert performance using hierarchic marking menus. *Proceedings of the INTERCHI '93*, 482-487. New York: ACM.

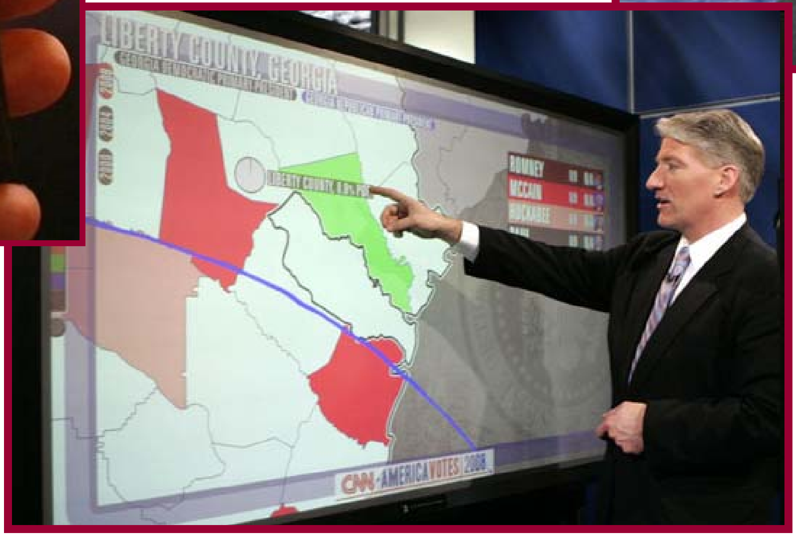
GEdit[1]



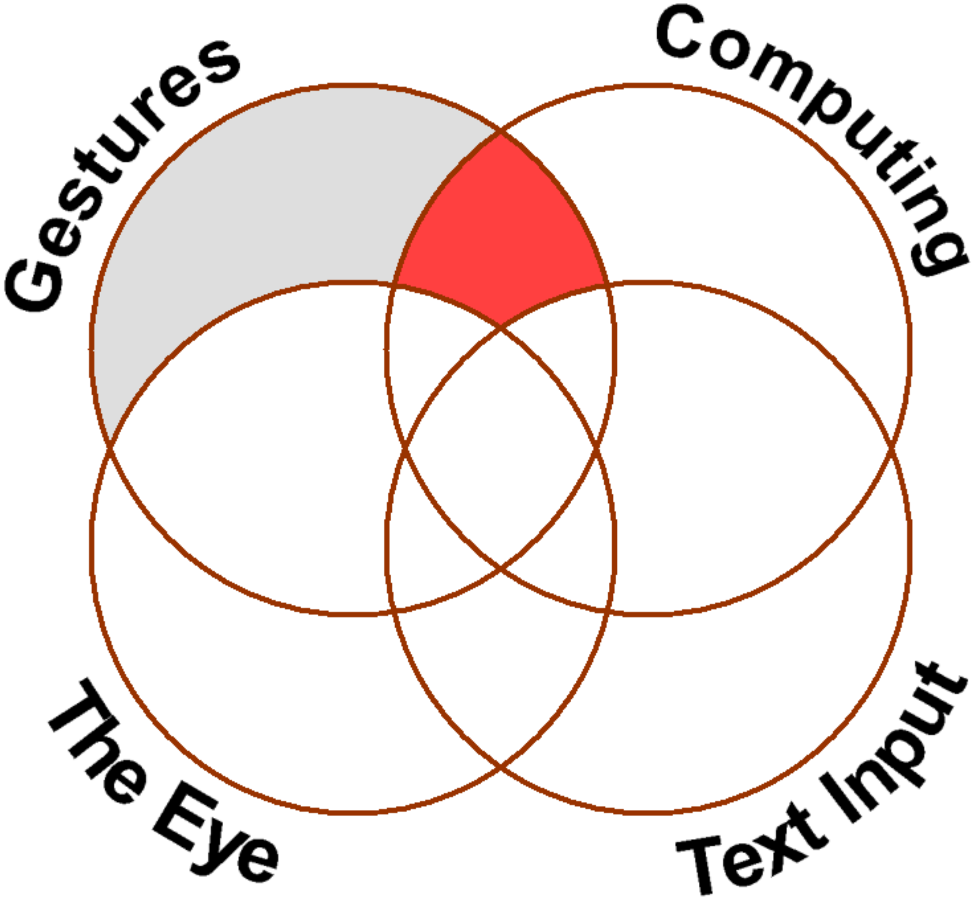
[1] Kurtenbach, G., & Buxton, W. (1991). GEdit: A testbed for editing by contiguous gesture. *SIGCHI Bulletin, 23*(2), 22-26.

Today

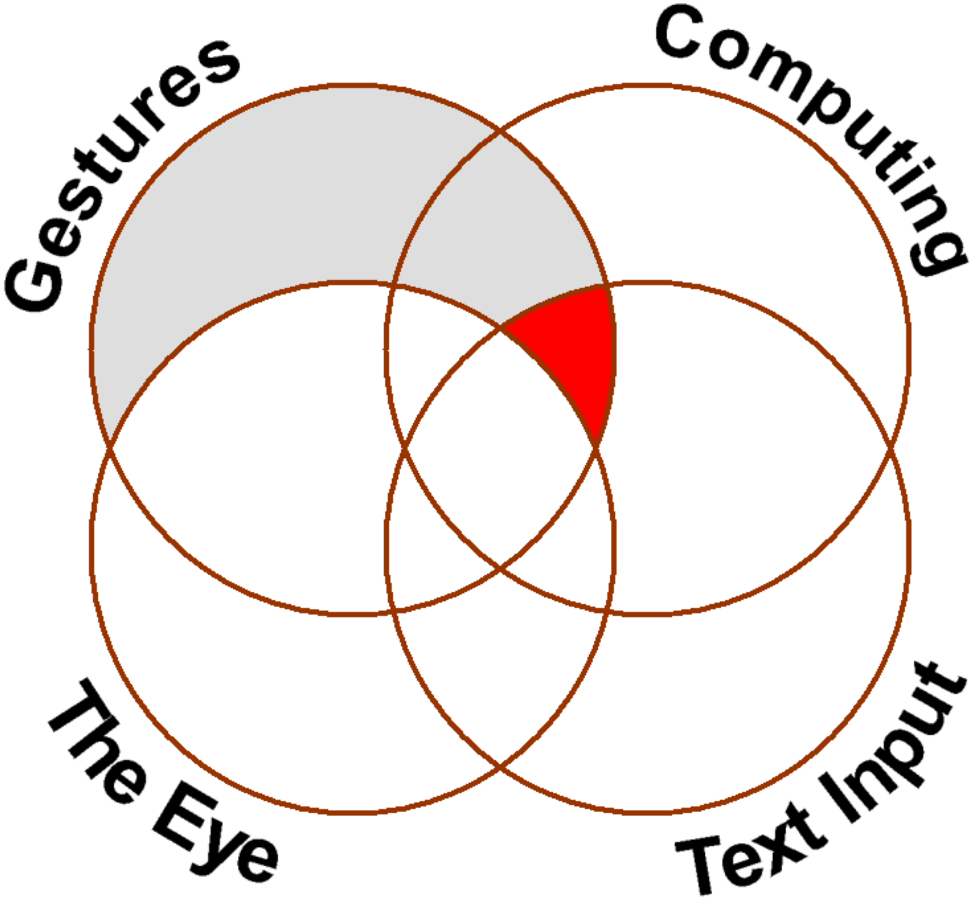

321
1 2 3
5 6
8 9
0+ C
SEND


LIBERTY COUNTY, GEORGIA
ROMNEY
MCCAIN
HUCKABEE
CNN AMERICA VOTES 2008

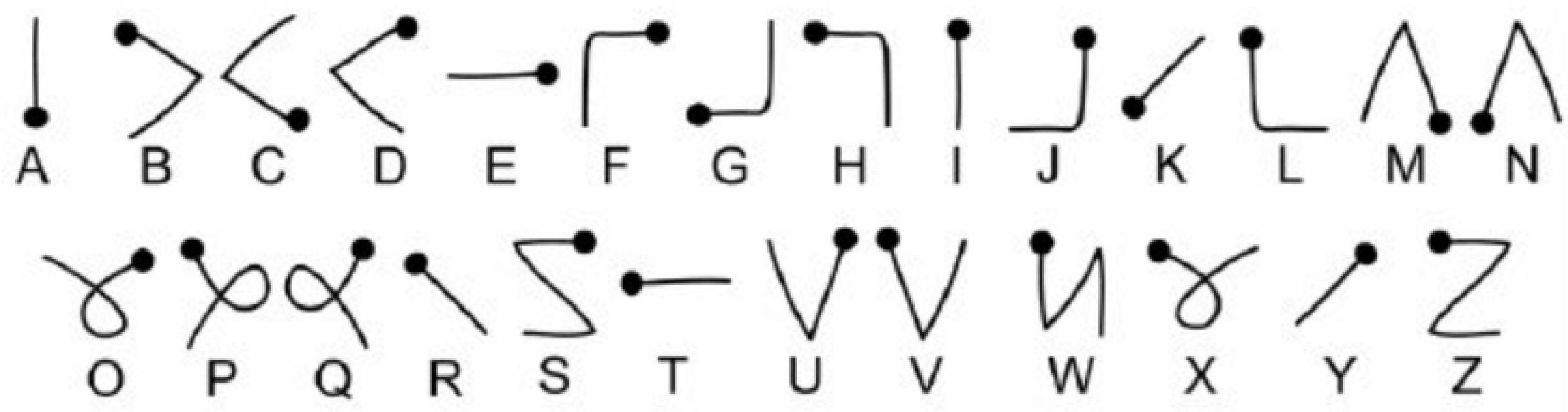
Eye Typing With Gestures



Eye Typing With Gestures

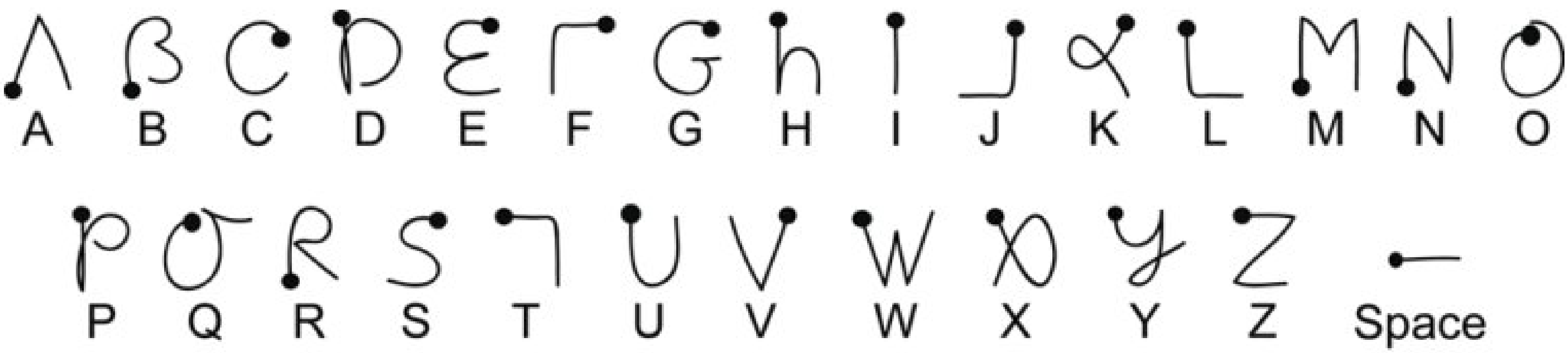


Unistrokes[1]



[1] Goldberg, D., & Richardson, C. (1993). Touch-typing with a stylus. *Proceedings INTERCHI '93*, 80-87. New York: ACM.

Graffiti



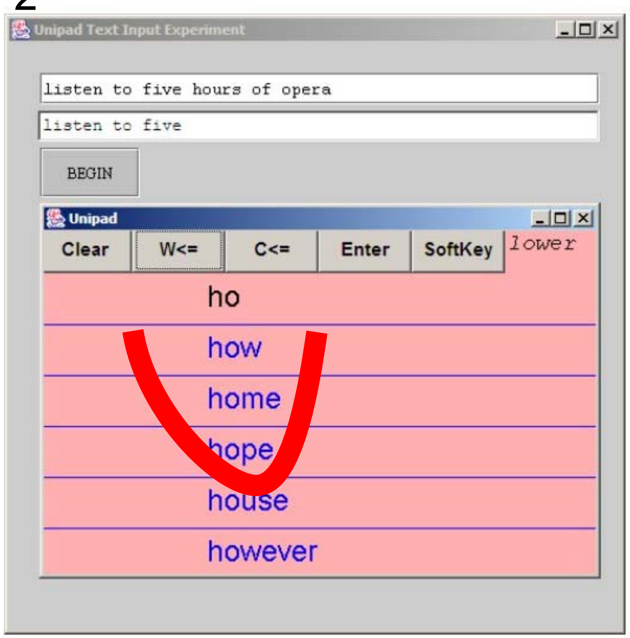
96% accuracy after five minutes[1]

[1] MacKenzie, I. S., & Zhang, S. (1997). The immediate usability of Graffiti. *Proceedings of Graphics Interface '97*, pp. 129-137. Toronto: Canadian Information Processing Society.

Graffiti Research

1

2



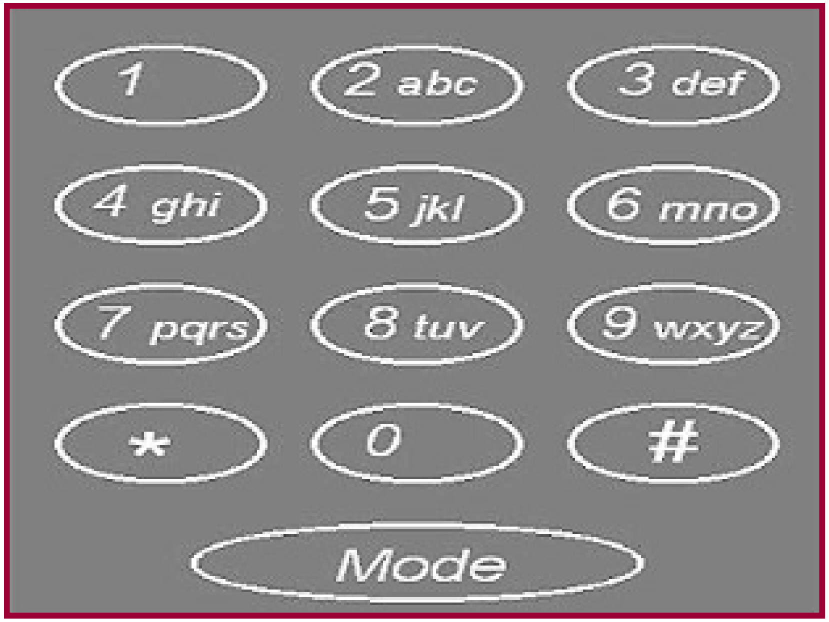
3

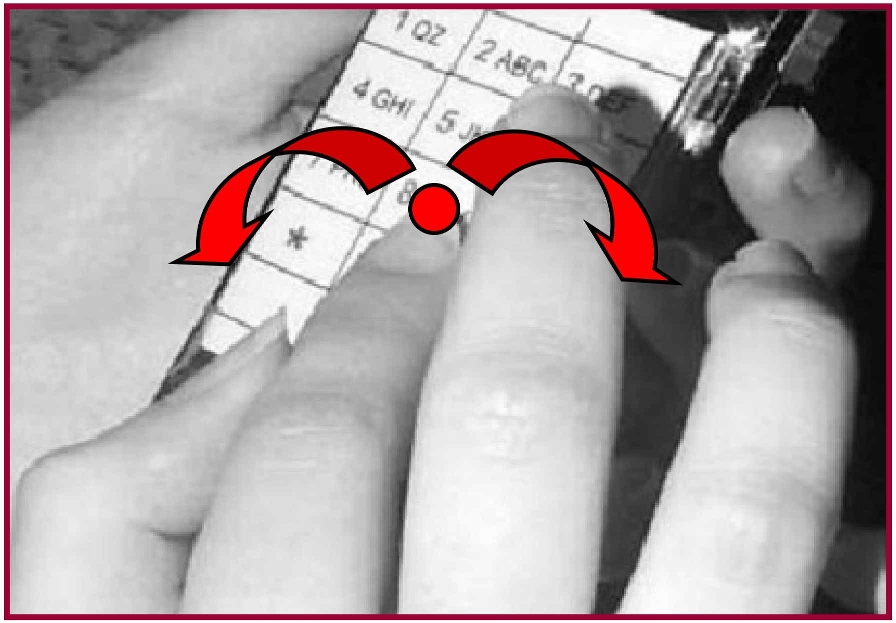
[1] Enns, N., & MacKenzie, I. S. (1998). Touch-based remote control devices. *Ext Abstracts of CHI '98*, 229-230. New York: ACM.

[2] MacKenzie, I. S., Chen, J., & Oniszczak, A. (2006). Unipad: Single-stroke text entry with language-based acceleration. *Proceedings of NordiCHI 2006*, 78-85. New York: ACM.

[3] Tinwala, H., & MacKenzie, I. S. (2009). Eyes-free text entry on a touchscreen phone. *Proceedings of TIC-STH 2009*, 83-88. New York: IEEE.

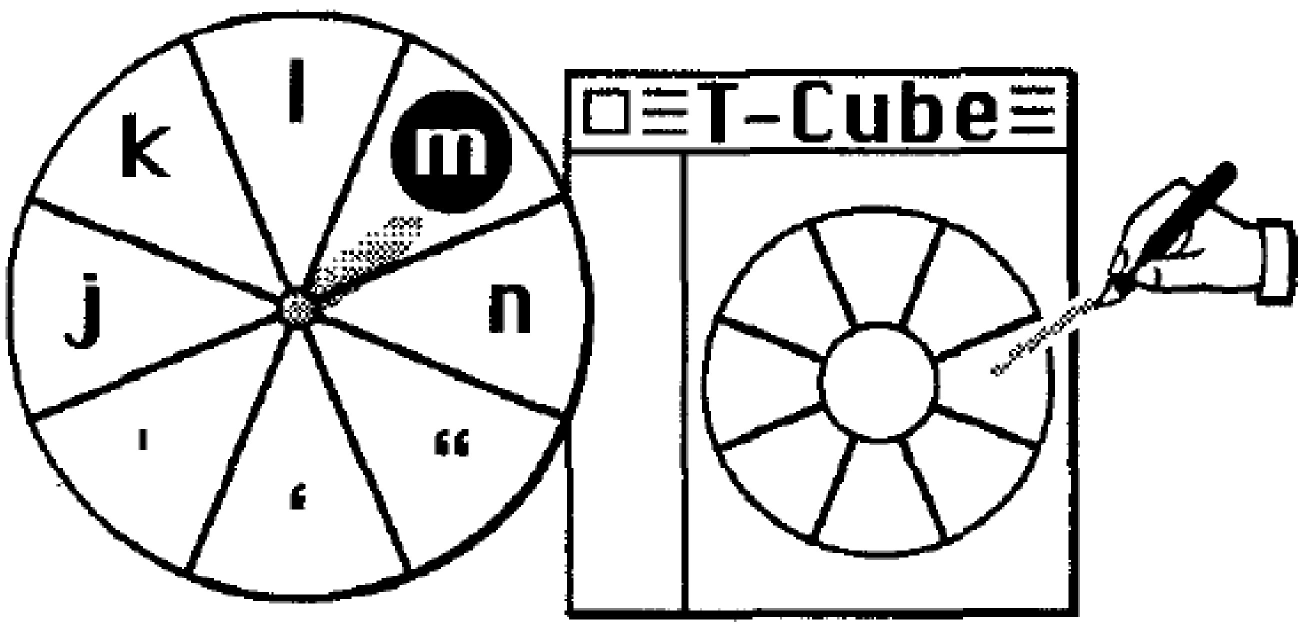
RollPad[1]





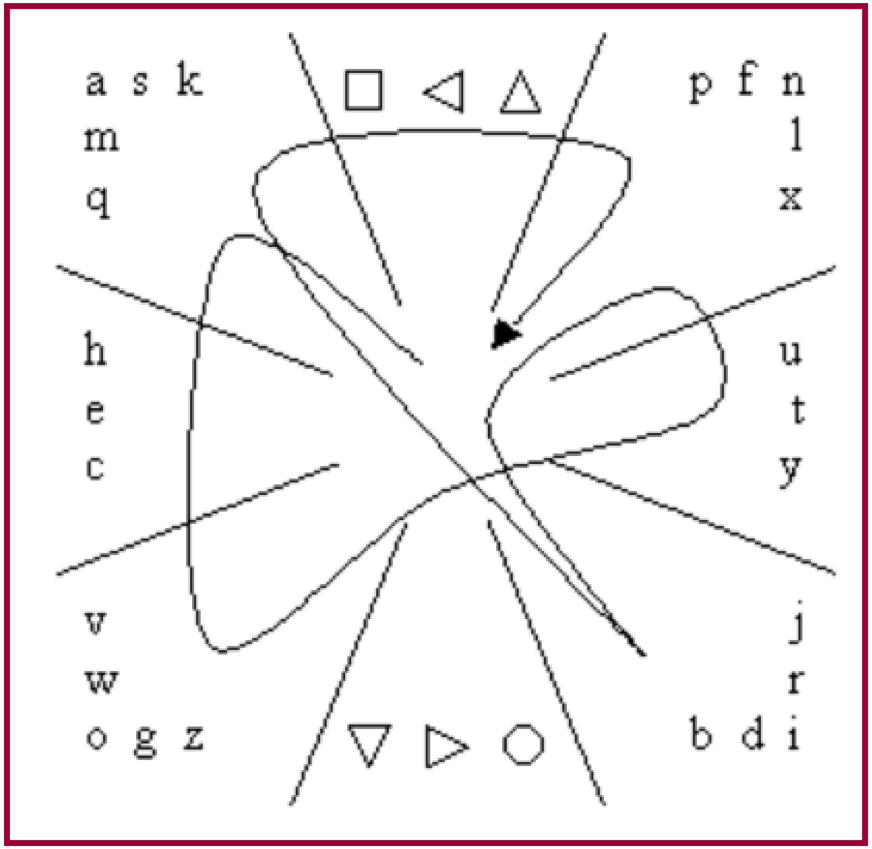
[1] Oniszczak, A., & MacKenzie, I. S. (2004). A comparison of two input methods for keypads on mobile devices. *Proceedings of NordiCHI 2004*, 101-104. New York: ACM..

T-Cube[1]



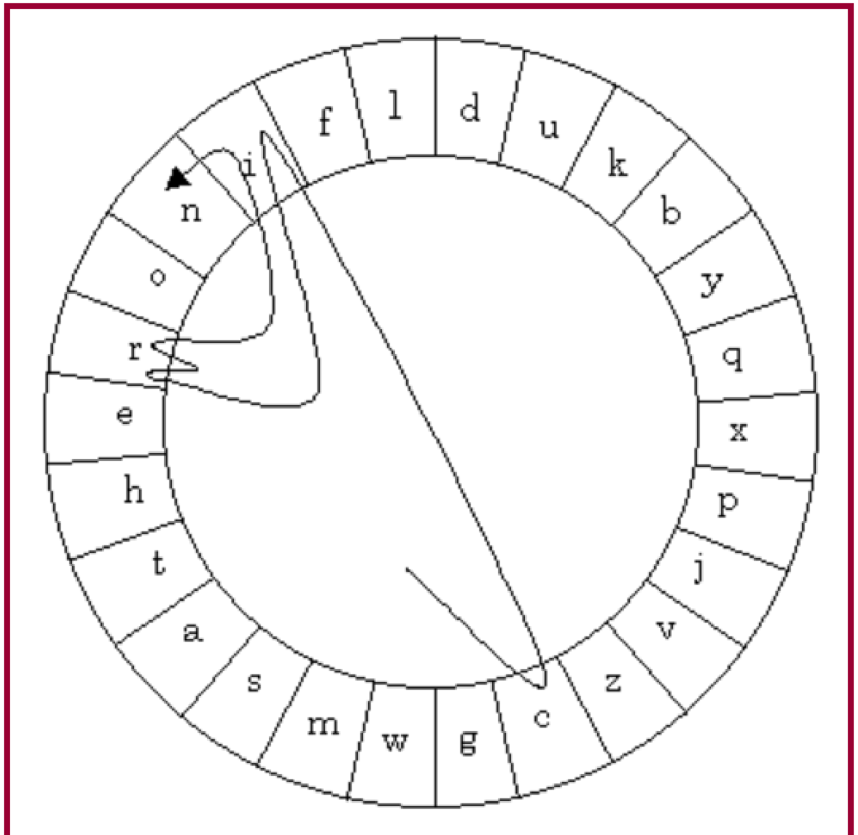
[1] Venolia, D., & Neiberg, F. (1994). T-Cube: A fast, self-disclosing pen-based alphabet. *Proceedings of CHI '94*, 265-270. New York: ACM.

QuikWriting[1]



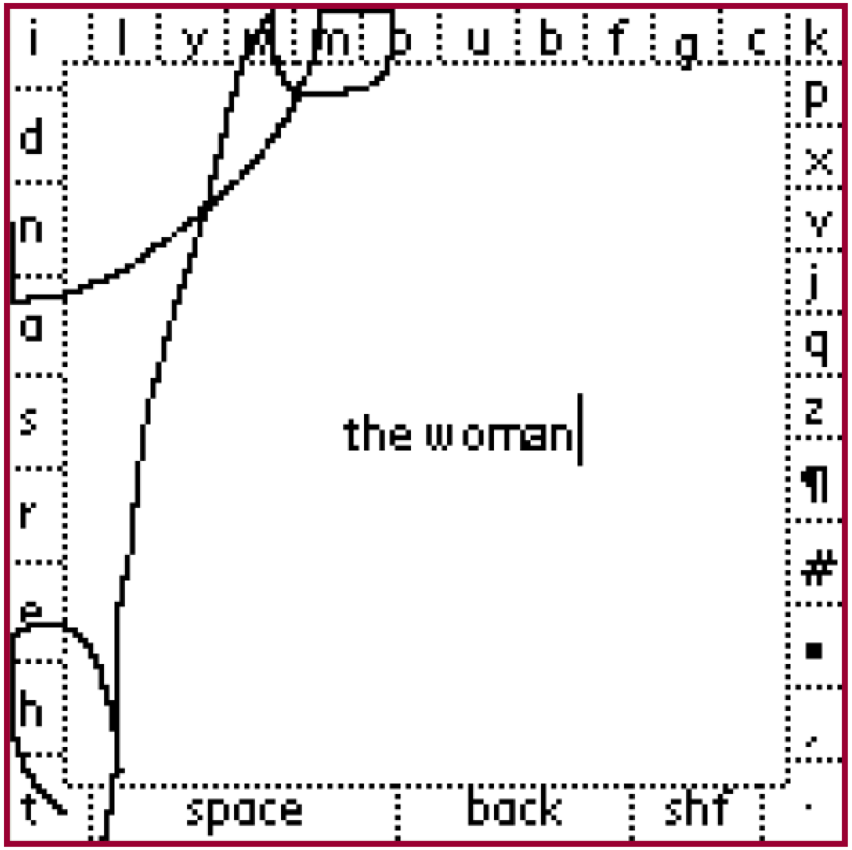
[1] Perlin, K. (1998). Quikwriting: Continuous stylus-based text entry. *Proceedings of UIST '98*, 215-216. New York: ACM.

Cirrin[1]



[1] Mankoff, J., & Abowd, G. A. (1998). Cirrin: A word-level unistroke keyboard for pen input, *Proceedings of UIST '98* (pp. 213-214): New York: ACM.

Edge Keyboard[1]

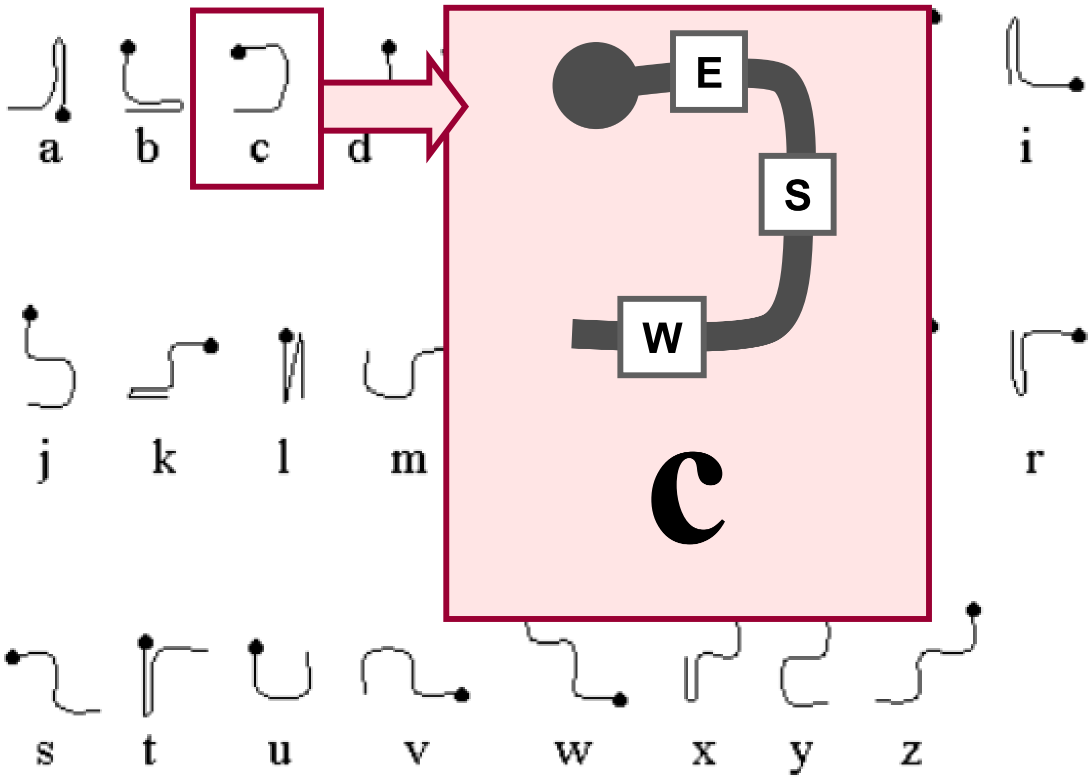


[1] Wobbrock, J. O., Myers, B. A., & Hudson, S. E. (2003). Exploring edge-based input techniques for handheld text entry. *Proceedings of ICDCS 2003*, 280-282. New York: IEEE.

MDITIM[1]

Four strokes

- **North**
- **South**
- **East**
- **West**

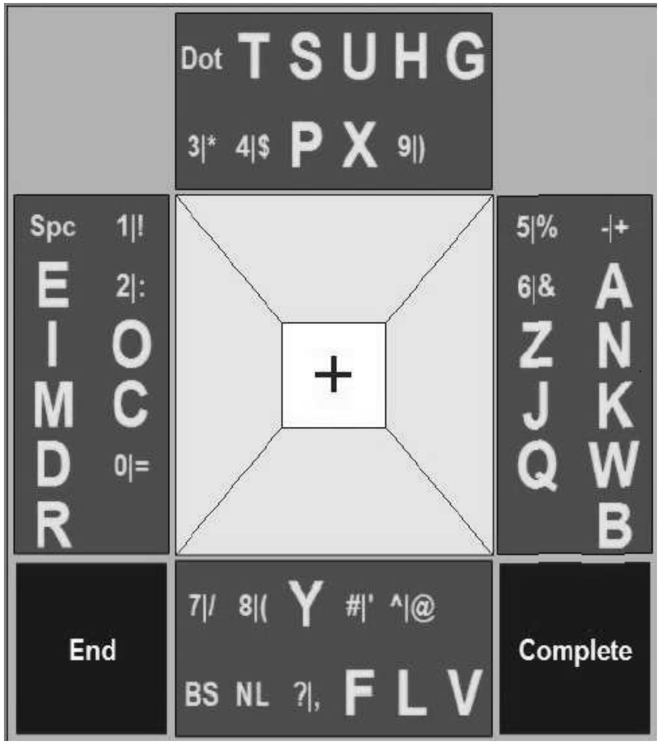


[1] Isokoski, P., & Raisamo, R. (2000). Device independent text input: A rationale and an example*. Proceedings of the Working Conference on Advanced Visual Interfaces - AVI 2000*, 76-83. New York: ACM.

LURD-Writer[1]

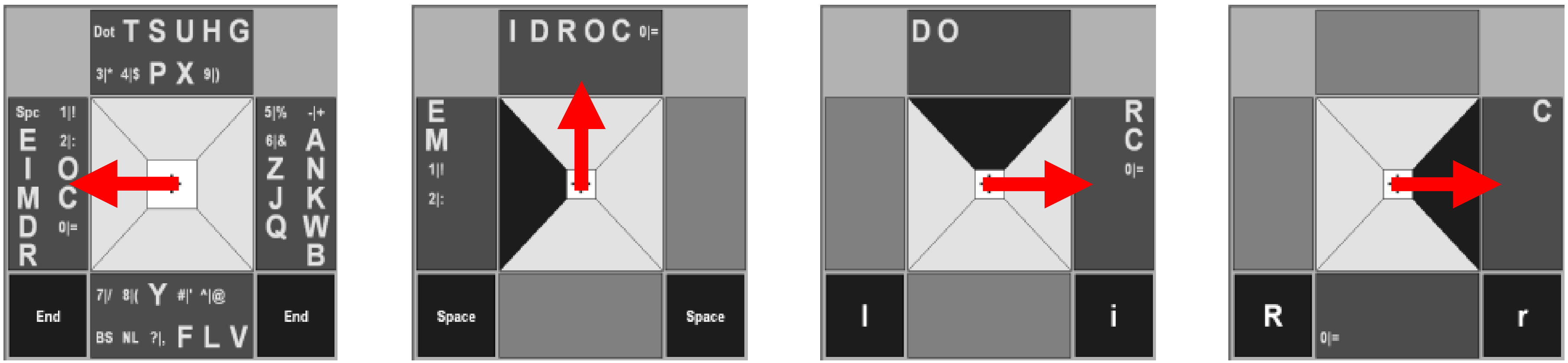
Four strokes

- **Left**
- **Up**
- **Right**
- **Down**

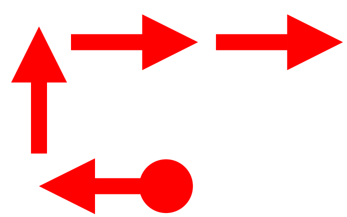


[1] Felzer, T., & Nordmann, R. (2006). Alternative text entry using different input methods. *Proceedings of ASSETS 2006*, 10-17. New York: ACM.

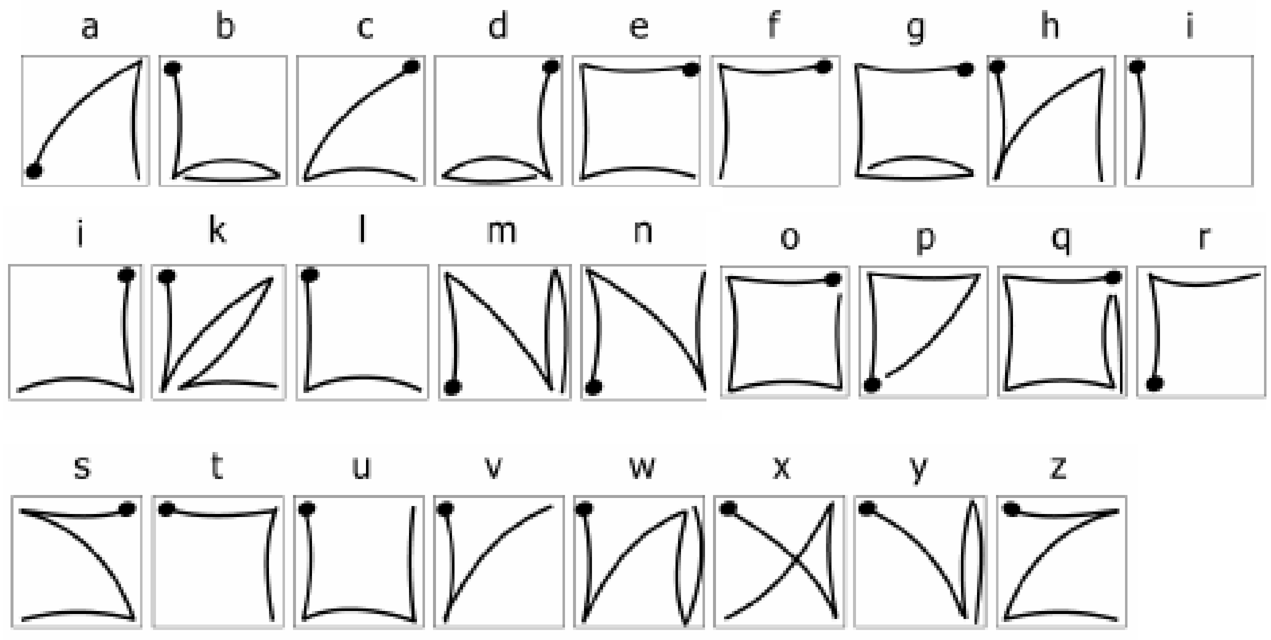
LURD-Writer "c"



"c" = L U R R

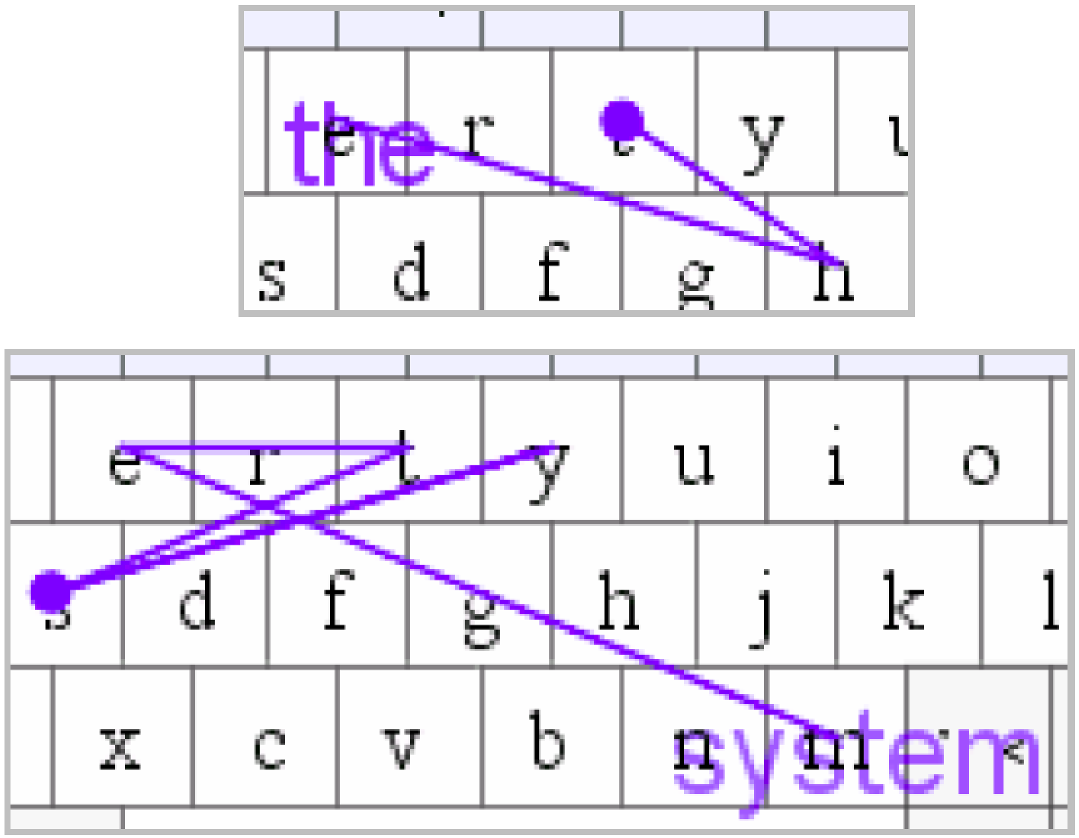


EdgeWrite[1]



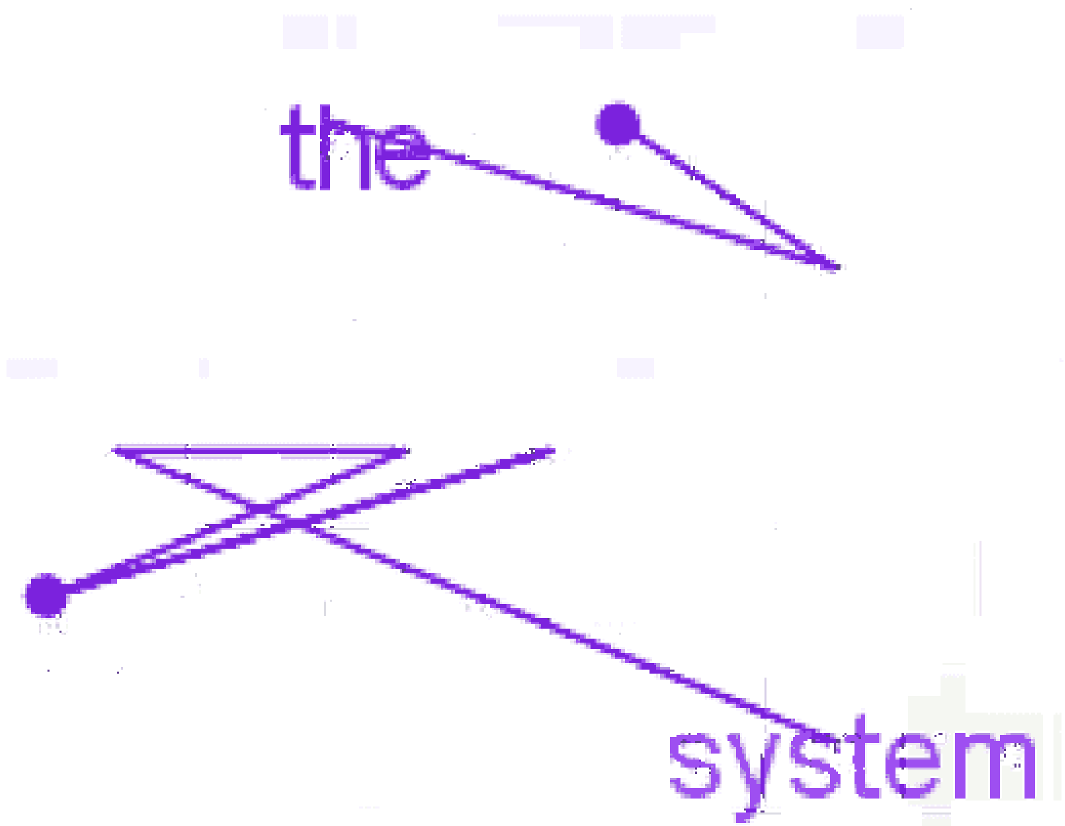
[1] Wobbrock, J. O., Myers, B. A., & Kembel, J. A. (2003). EdgeWrite: A stylus-based text entry method designed for high accuracy and stability of motion. *Proceedings of UIST 2003*, 61-70. New York: ACM.

Shape Writing[1]



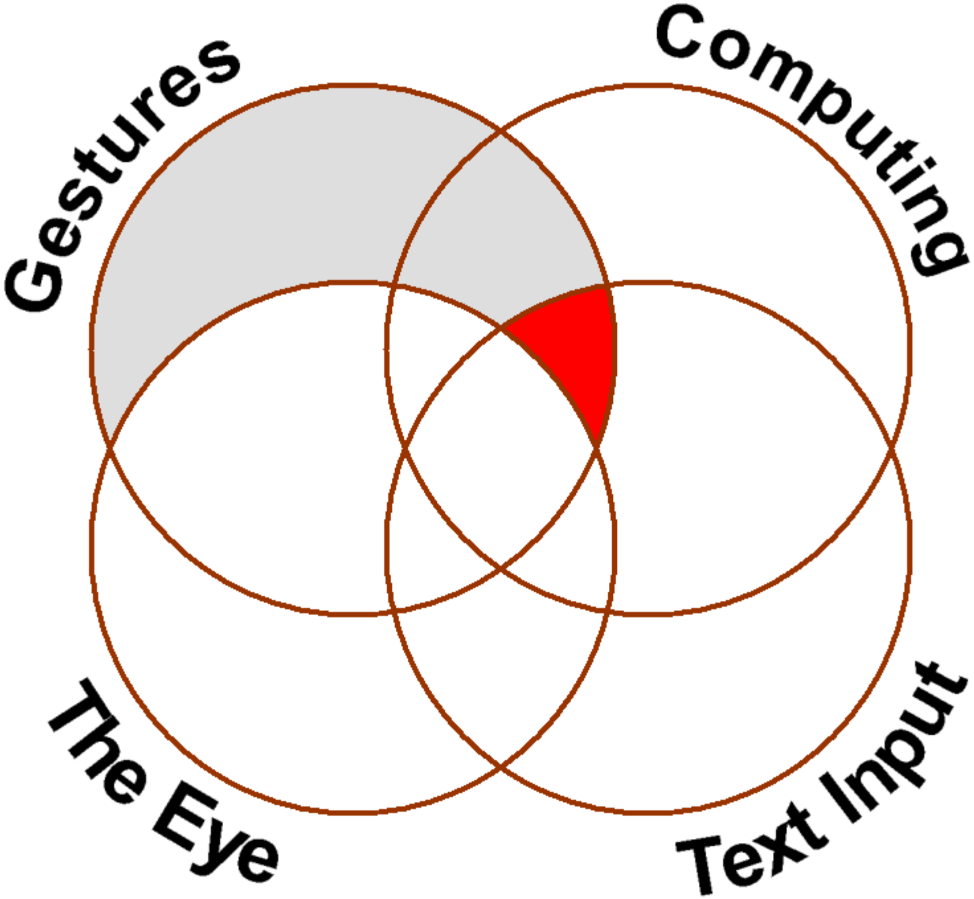
[1] Zhai, S., & Kristensson, P.-O. (2007). Learning shape writing by game playing. *Ext Abstracts of CHI 2007*, 1971-1976. New York: ACM.

Shape Writing[1]

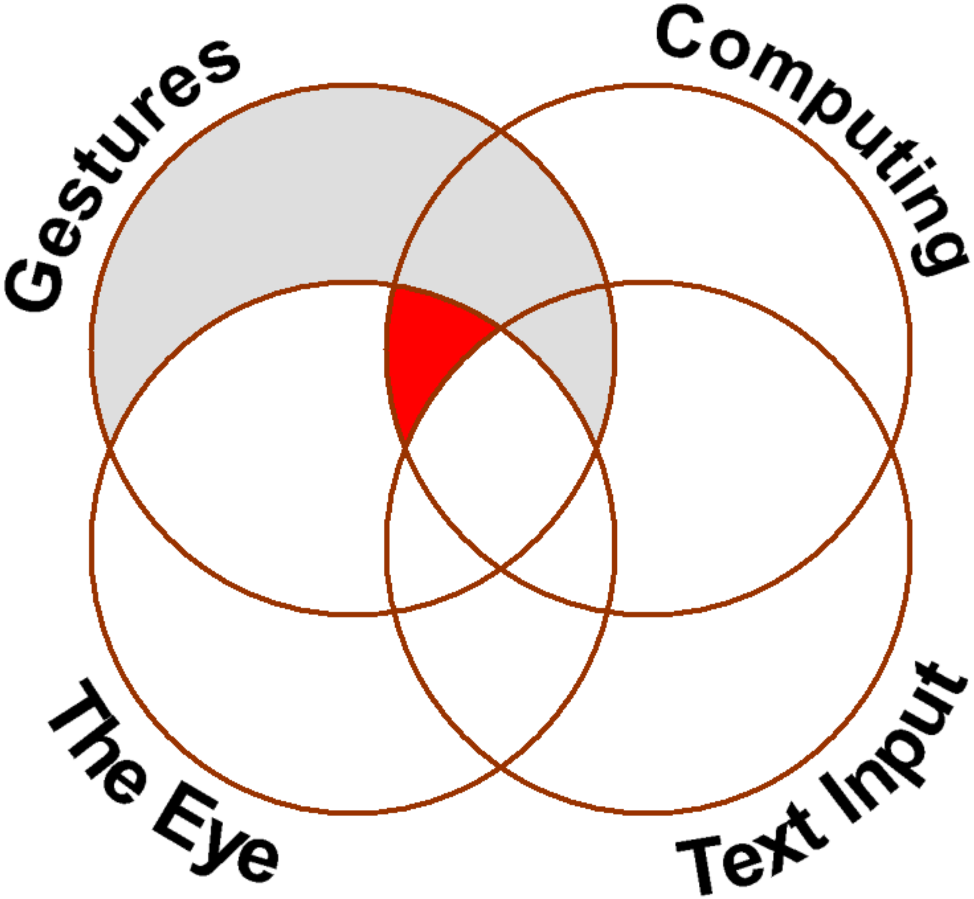


[1] Zhai, S., & Kristensson, P.-O. (2007). Learning shape writing by game playing. *Ext Abstracts of CHI 2007*, 1971-1976. New York: ACM.

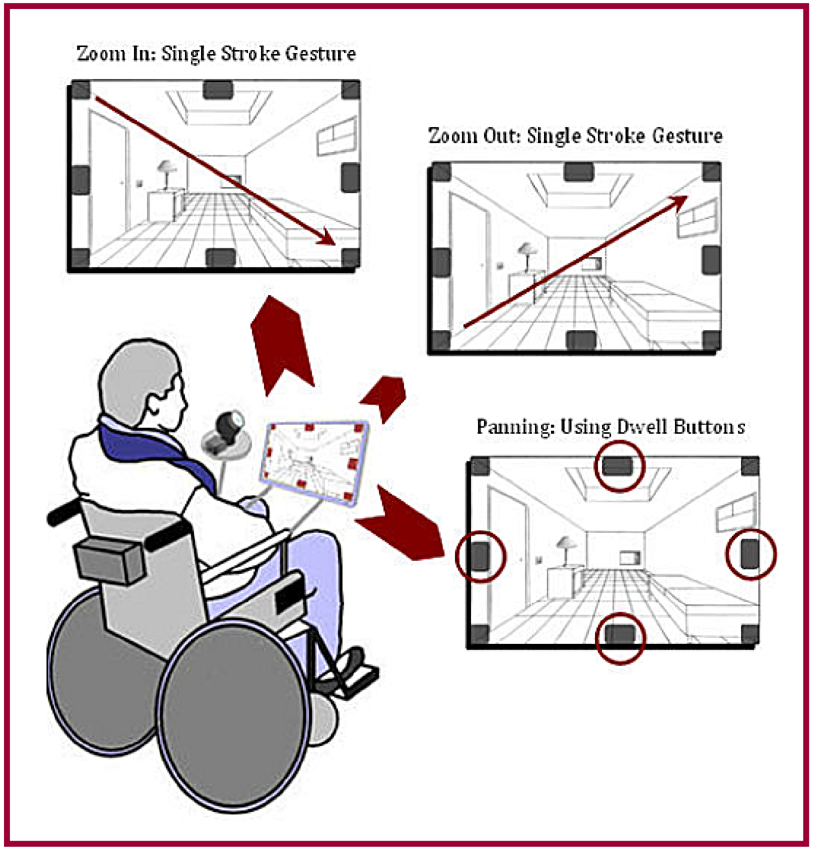
Eye Typing With Gestures

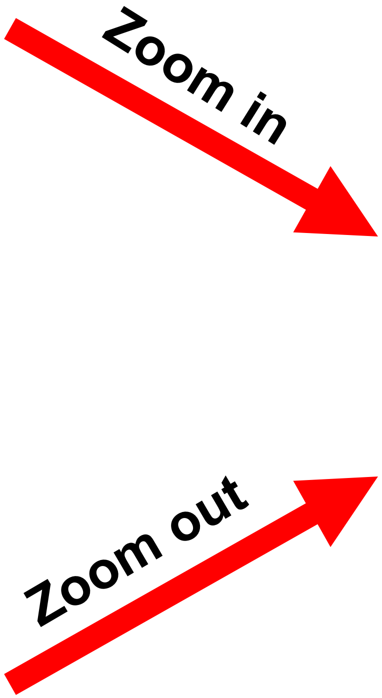


Eye Typing With Gestures



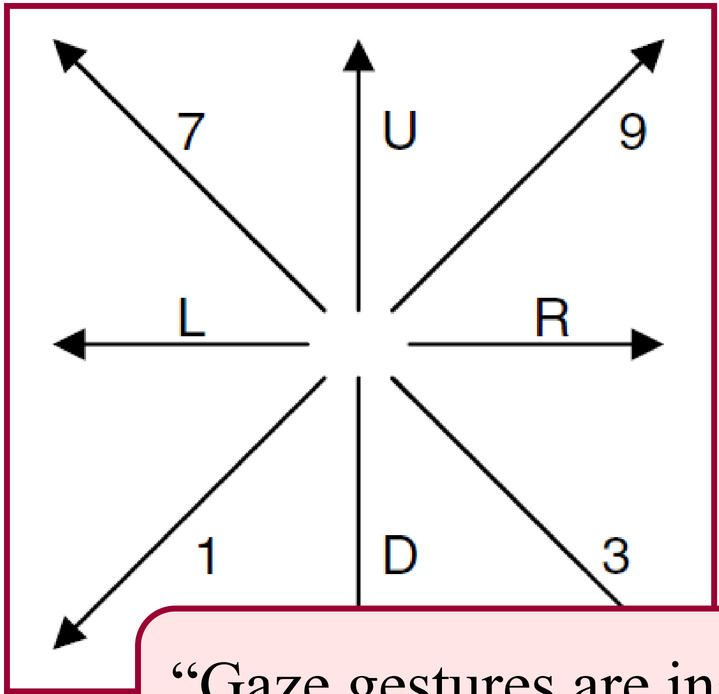
Virtual World Navigation[1]

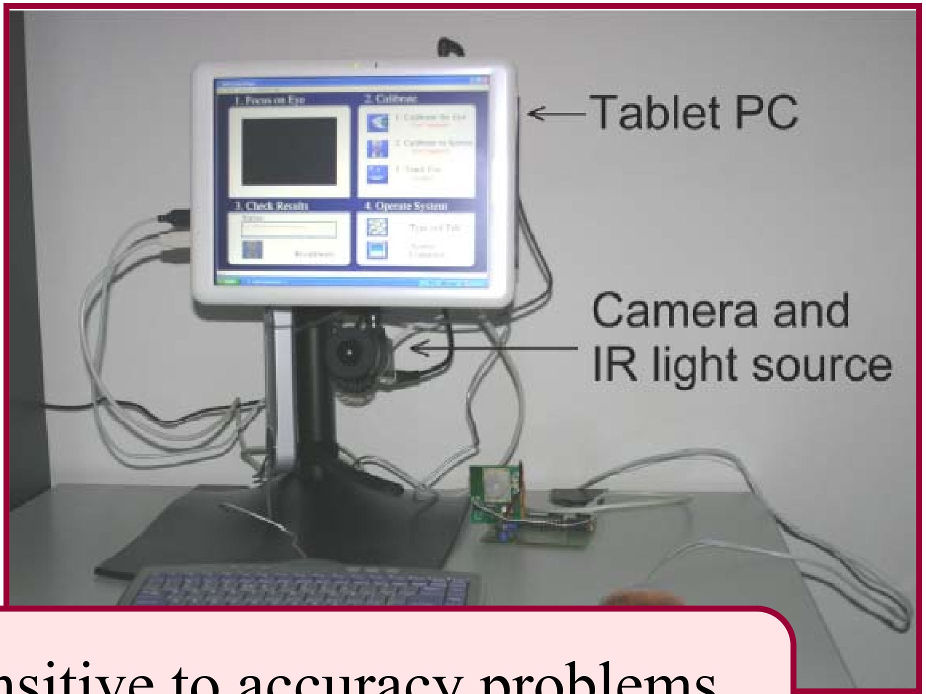




[1] Mollenbach, E., Hansen, J. P., Lillholm, M., & Gale, A. G. (2009). Single stroke gaze gestures. *Ext Abstracts of CHI 2009*, 4555-4560. New York: ACM.

Eye Gestures Commands[1]





"Gaze gestures are insensitive to accuracy problems and immune against calibration shift."

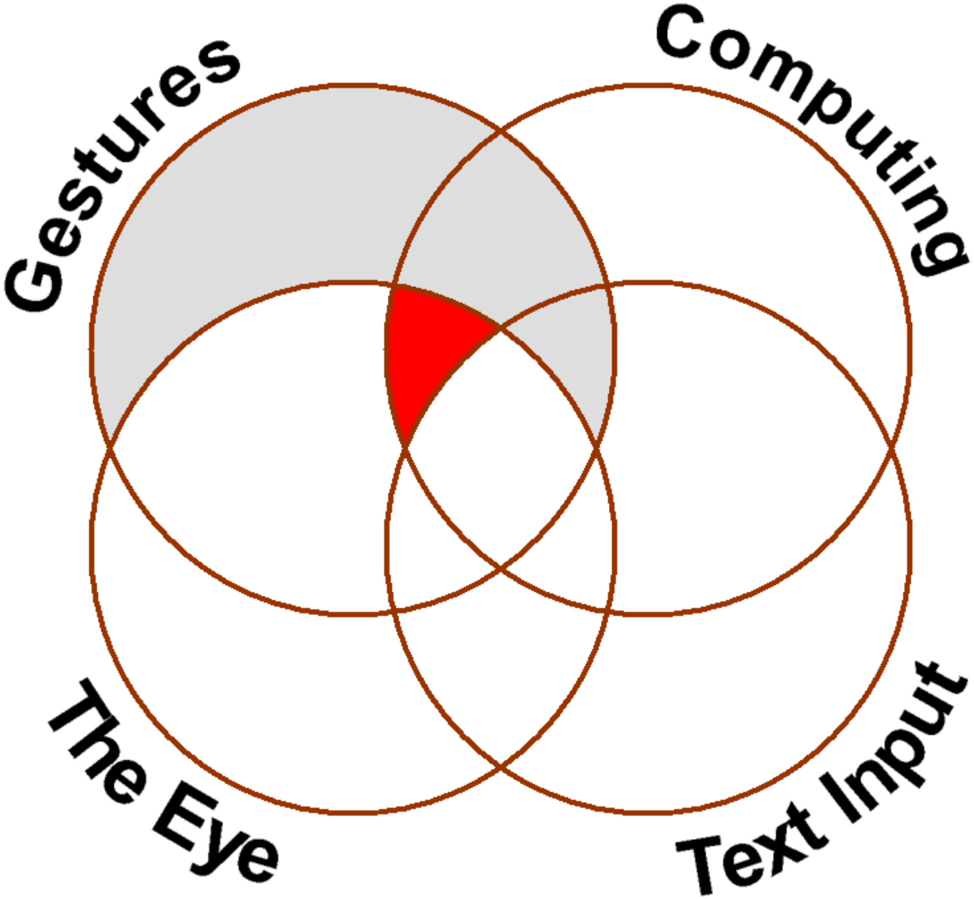
[1] Drewes, H., & Schmidt, A. (2007). Interacting with the computer using gaze gestures. *Proceedings of INTERACT 2007*, 475-488. Berlin: Springer.

Mode Switching[1]

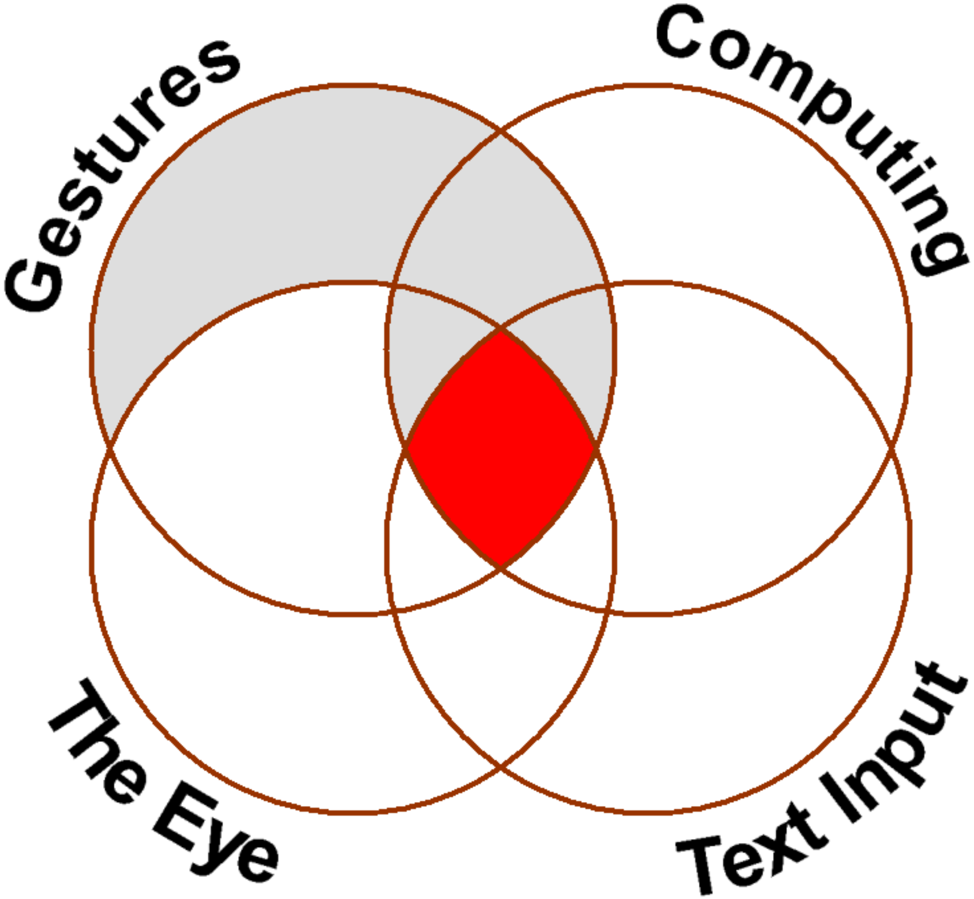
Mode	Eye Control Off	Dwell Click	Park it Here	Drag from Here
Eye gesture to enter the mode	glance up	glance left	glance right	glance down

[1] Istance, H., Bates, R., Hyrskykari, A., & Vickers, S. (2008). Snap clutch: A moded approach to solving the Midas touch problem. *Proceedings of ETRA 2008*, 221-228. New York: ACM.

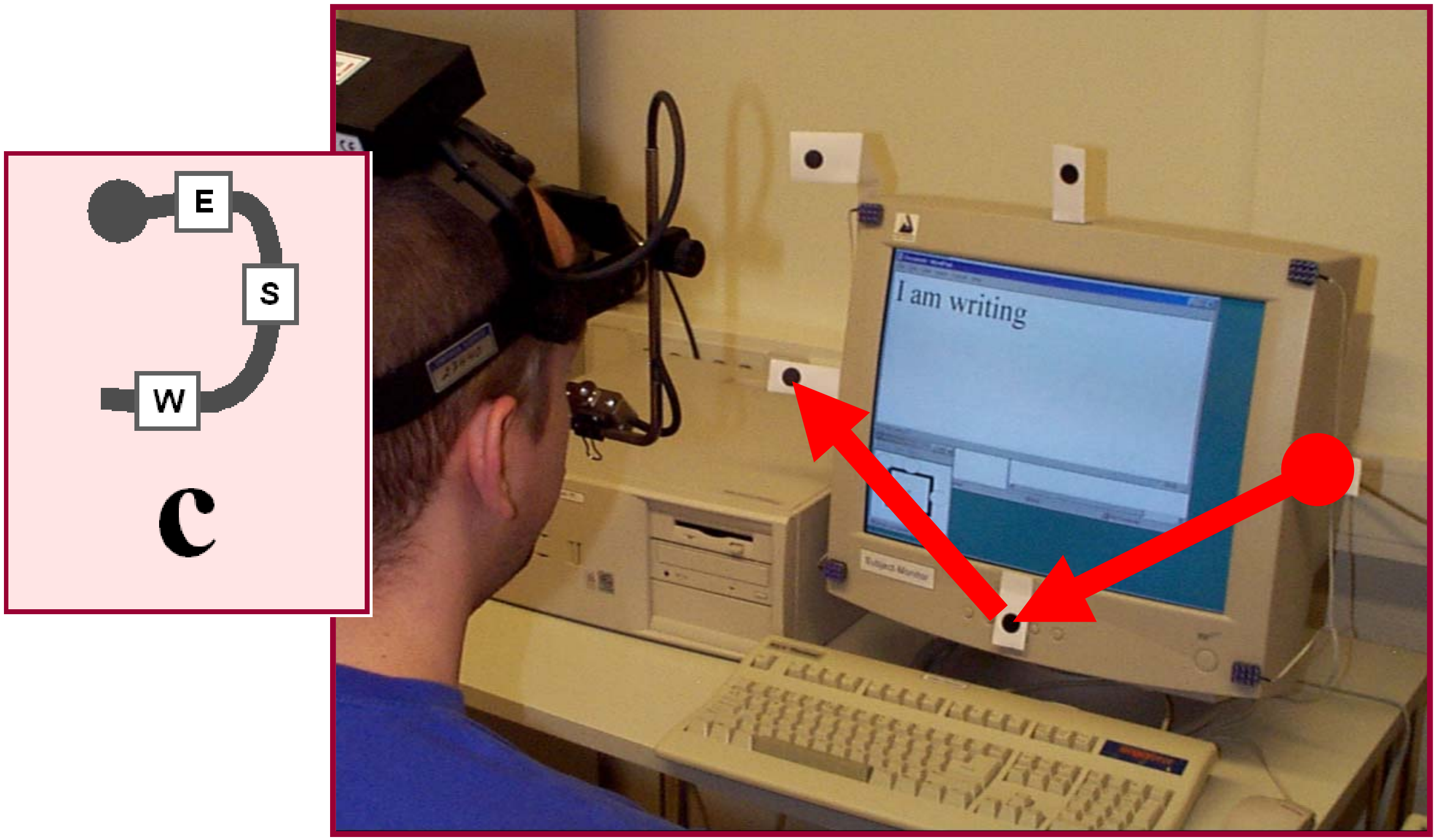
Eye Typing With Gestures



Eye Typing With Gestures

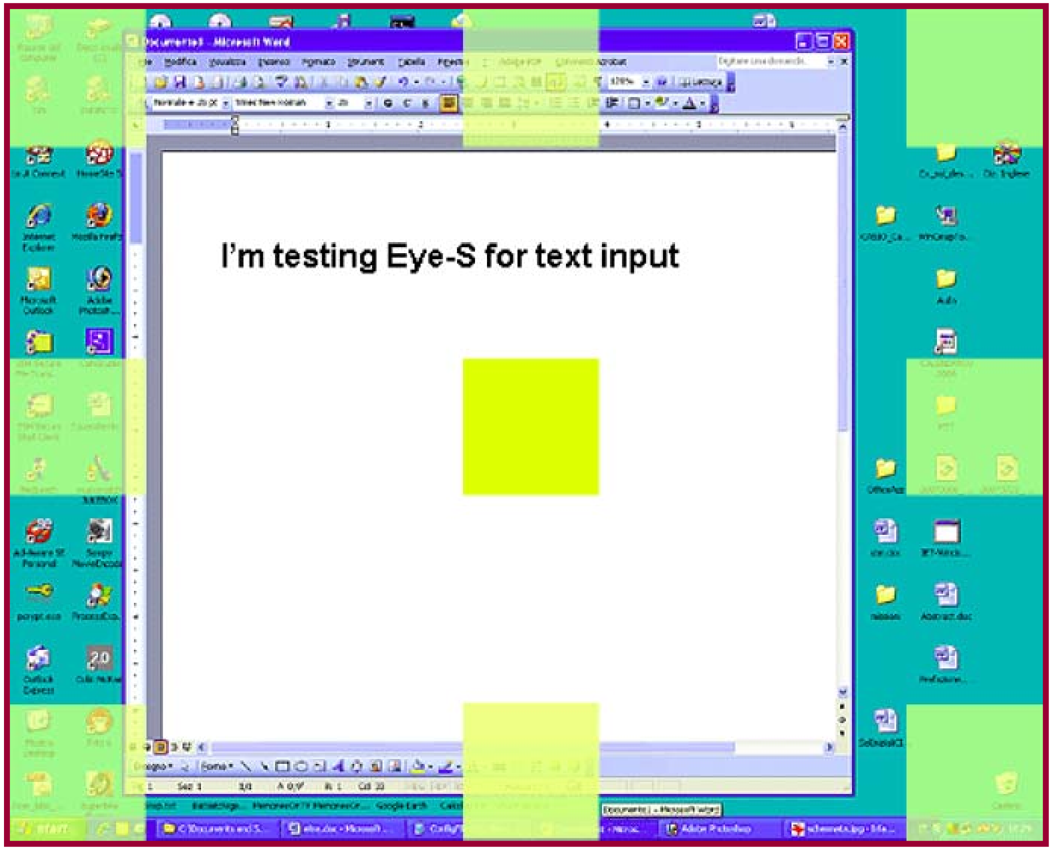


MDITIM[1]



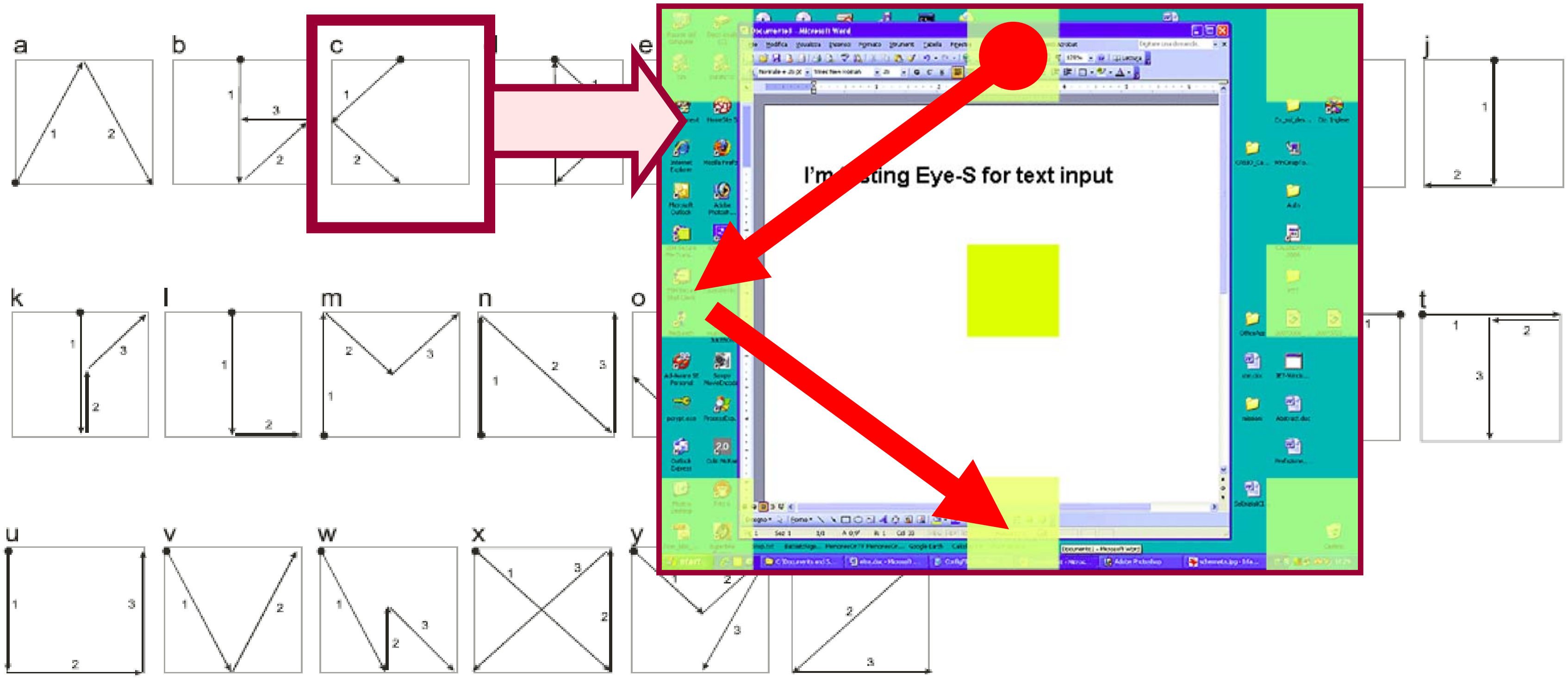
[1] Isokoski, P. (2000). Text input methods for eye trackers using off-screen targets. *Proceedings of ETRA 2000*, 15-21. New York: ACM.

Eye-S[1]

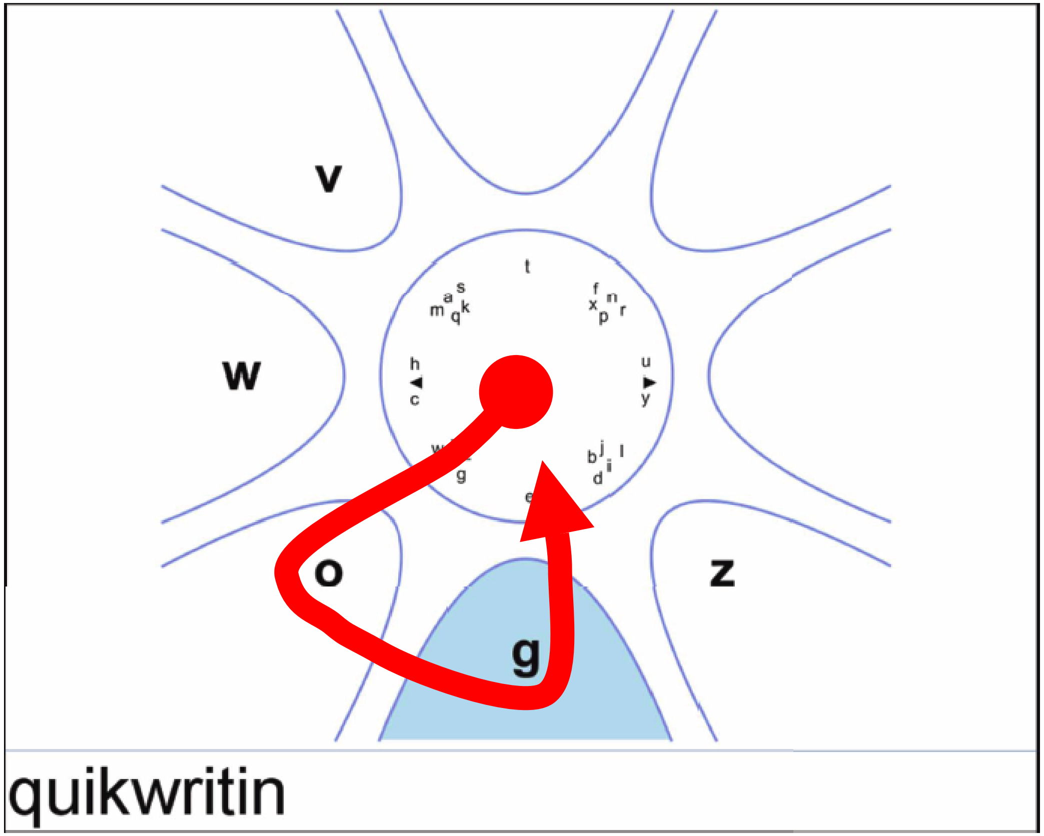


[1] Porta, M., & Turina, M. (2008). Eye-S: A full-screen input modality for pure eye-based communication. *Proceedings of ETRA 2008*, 27-34. New York: ACM.

Eye-S Alphabet

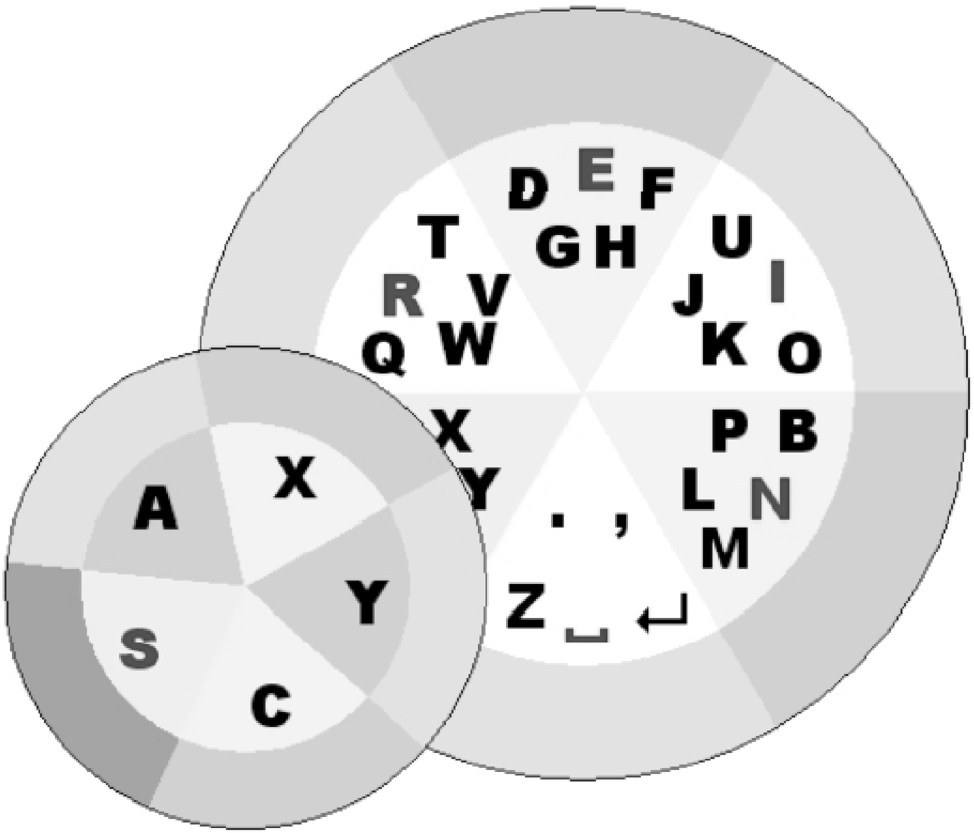


Quik(Eye)Writing[1]



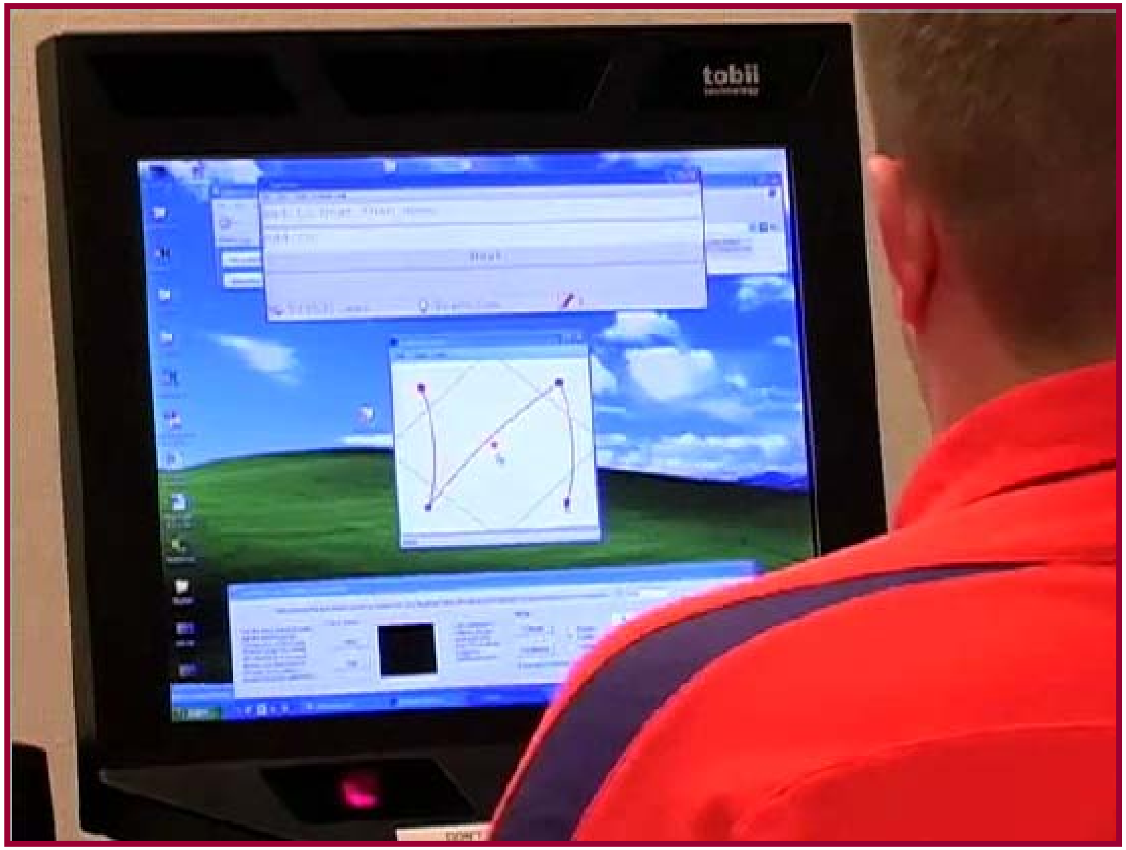
[1] Bee, N., & Andre, E. (2008). Writing with your eye: A dwell time free writing system adapted to the nature of human eye gaze. In Andre et al (Eds), *Perception in Multimodal Dialogue Systems* (pp. 111-122): Berlin: Springer.

pEYEwrite[1]



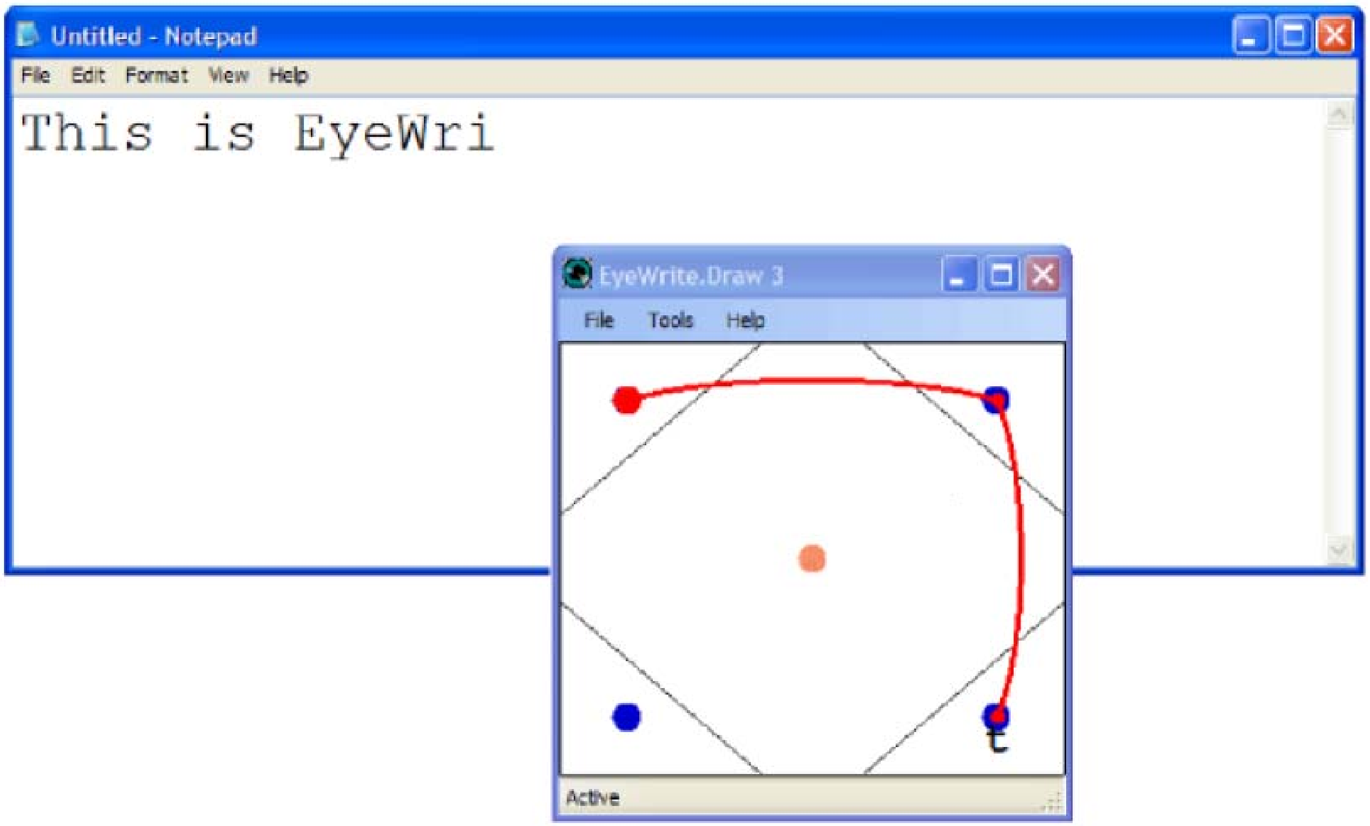
[1]Huckauf, A., & Urbina, M. H. (2008). Gazing with pEYEs: Towards a universal input for various applications. *Proceedings of ETRA 2008*, 51-54. New York: ACM..

EyeWrite[1]

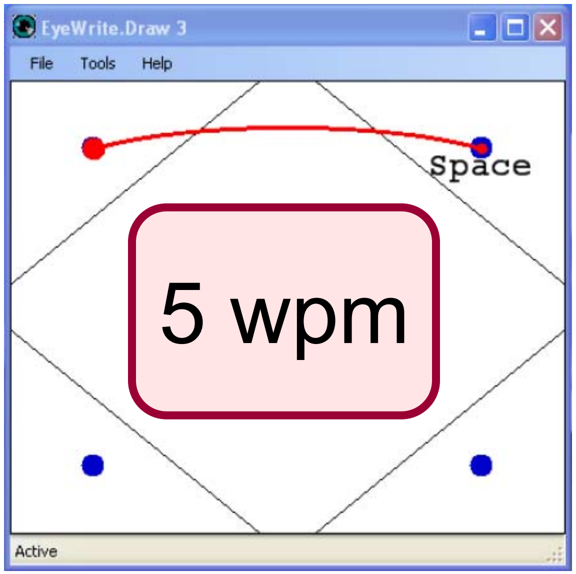


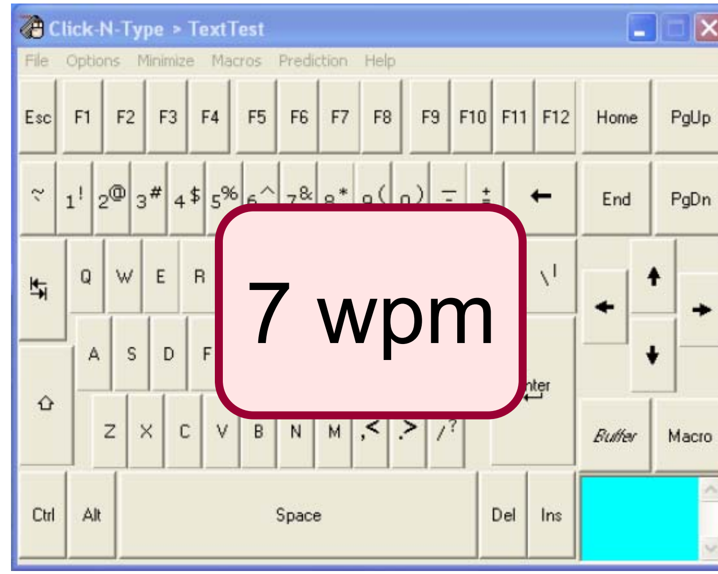
[1] Wobbrock, J. O., Rubinstein, J., Sawyer, M. W., & Duchowski, A. T. (2008). Longitudinal evaluation of discrete consecutive gaze gestures for text entry. *Proceedings of ETRA 2008*, 11-18, 281. New York: ACM.

Gaze Gestures + EdgeWrite = EyeWrite



EyeWrite vs. On-screen Keyboard





From the abstract…

R sults from the second longitudi-nal study indicate that EyeW nherent multi-saccade handicap (4.52 saccades per character uency-weighted average) is suf-ficient for the on-screen key to edge out EyeWrite in speed performance.

!

Saccades per Character = *KSPC*[1]

- Keystrokes per character (*KSPC*)
  - Definition:

> *The average number of keystrokes required to produce each character of text in a given language using a given interaction technique*

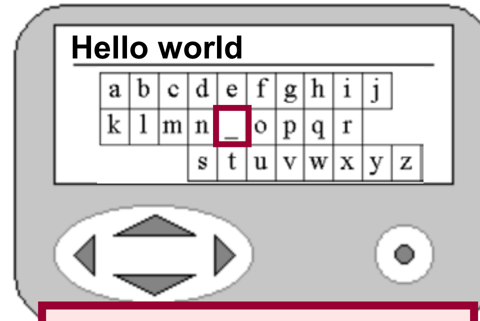
  - Note: "Keystrokes" can be any primitive action; e.g., stylus or finger stroke, gesture, timeout, saccade, dwell, tap, touch, swipe, flick, nod, blink, wink, …

[1] MacKenzie, I. S. (2002). KSPC (keystrokes per character) as a characteristic of text entry techniques. *Proceedings of MobileHCI 2002*, 195-210. Berlin: Springer.

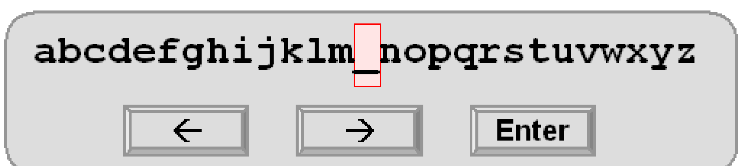
KSPC Examples[1]

KSPC = 1.0

KSPC = 2.032 (multitap)
KSPC = 1.007 (T9)



KSPC = 3.132



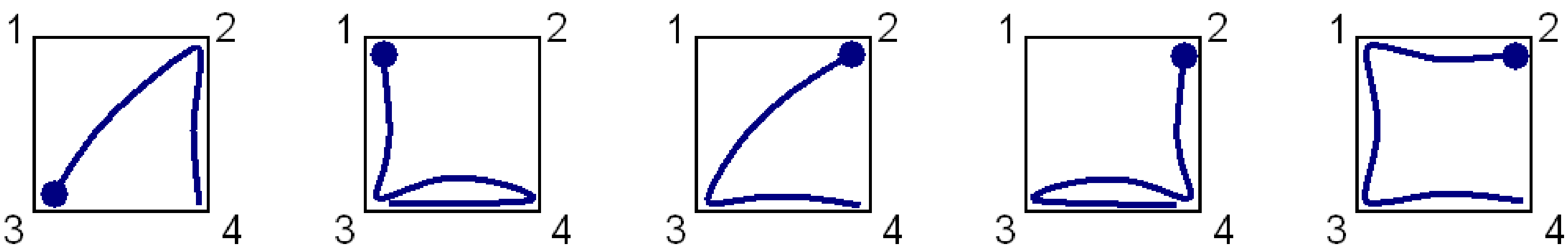
KSPC = 6.446

KSPC = 1.405 (multitap)
KSPC = 1.002 (T9)

[1] MacKenzie, I. S., & Tanaka-Ishii, K. (2007). Text entry with a small number of buttons. In I. S. MacKenzie, and Tanaka-Ishii, K. (Ed.), *Text entry systems: Mobility, accessibility, universality* (pp. 105-121): San Francisco, Morgan Kaufmann.

EdgeWrite “Keystrokes” or “Codes”

a b c d e



etc.

324 1343 234 2434 2134

EdgeWrite *KSPC*

Character	*p*	EdgeWrite Code	Code Length	*p* x length
_	0.1843	21	2	0.3685
e	0.1028	2134	4	0.4111
t	0.0778	124	3	0.2334
a	0.0661	324	3	0.1982
o	0.0629	21342	5	0.3147
i	0.0592	13	2	0.1183
n	0.0580	3142	4	0.2321
s	0.0517	2143	4	0.2067
h	0.0490	1324	4	0.1958
r	0.0485	213	3	0.1456
l	0.0318	134	3	0.0954
d	0.0293	2434	4	0.1172
c	0.0244	234	3	0.0731
u	0.0218	1342	4	0.0870
f	0.0203	213	3	0.0609
m	0.0200	31424	5	0.1002
w	0.0176	13242	5	0.0882
y	0.0160	1424	4	0.0641
p	0.0155	3123	4	0.0620
g	0.0139	21343	5	0.0697
b	0.0129	1343	4	0.0517
v	0.0077	134	3	0.0231
k	0.0047	13234	5	0.0233
x	0.0015	1423	4	0.0061
j	0.0013	243	3	0.0039
q	0.0008	213424	6	0.0048
z	0.0003	1234	4	0.0010
			KSPC =	3.3562

EdgeWrite *KSPC*

Character	*p*	EdgeWrite Code	Code Length	*p* x length
_	0.1843	21	2	0.3685
e	0.1028	2134	4	0.4111
t	0.0778	124	3	0.2334
[illegible]	[illegible]	324	3	0.1982
[illegible]	[illegible]	21342	[illegible]	0.3147
[illegible]	[illegible]	13	[illegible]	0.1183
[illegible]	0.0015	1423	4	0.0061
[illegible]	0.0013	243	3	0.0039
q	0.0008	213424	6	0.0048
z	0.0003	1234	4	0.0010
			KSPC =	3.3562

"Houston, we've got a problem!"

?

EdgeWrite *KSPC* (with delimiter)

Character	*p*	EdgeWrite(d) Code	Code Length	*p* x length
_	0.1843	21*	3	0.5528
e	0.1028	2134*	5	0.5139
t	0.0778	124*	4	0.3112
a	0.0661	324*	4	0.2643
o	0.0629	21342*	6	0.3777
i	[illegible]	[illegible]	3	0.1775
x	0.0015	1423*	5	[illegible]
j	0.0013	243*	4	0.0051
q	0.0008	213424*	7	0.0056
z	0.0003	1234*	5	0.0013
		* = delimiter	*KSPC* =	4.3562

Improving EdgeWrite

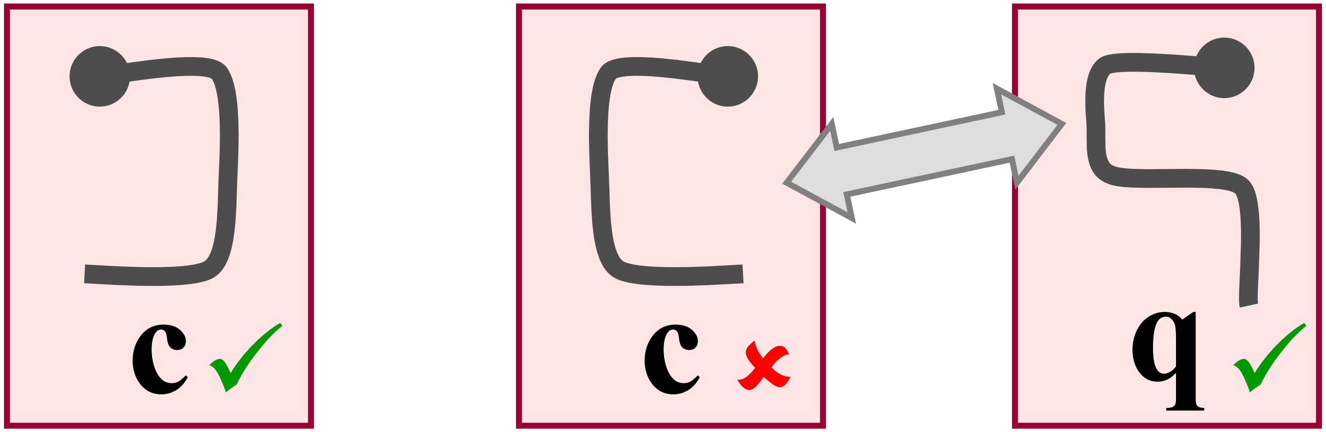
- The trick:
  - Reduce *KSPC* by simplifying codes
  - Eliminate need for a delimiter
- The goal:
  - Faster text entry speed
- The challenge:
  - Skill acquisition (i.e., remembering the codes)
- The win:
  - Shorter codes are easier to remember
  - E.g., EdgeWrite "e" → 2134
  - Requires four "digits"
  - Reduce to two "digits"

Prefix Codes

- Each code is both
  - Unique, and
  - A unique prefix
- Implication
  - The meaning of a code sequence can be unambiguously determined
  - No delimiter needed

Prefix Codes in Text Entry[1]

- Isokoski and Raisamo's *MDITIM* (minimal device independent text input method)
- All codes are prefix codes, and so…



[1] Isokoski, P., & Raisamo, R. (2000). Device independent text input: A rationale and an example. *Proceedings of AVI 2000*, 76-83. New York: ACM.

MDITIM *KSPC*

Character	*p*	MDITIM Code	Code Length	p x length
_	0.1843	NE	2	0.3685
e	0.1028	WES	3	0.3083
t	0.0778	SNE	3	0.2334
a	0.0661	NSW	3	0.1982
o	0.0629	WSEN	4	0.2518
i	0.0592	WNS	3	0.1775
n	0.0580	NSN	3	0.1741
s	0.0517	ESE	3	0.1550
h	0.0490	WSWS	4	0.1958
r	0.0485	WSN	3	0.1456
l	0.0318	SNS	3	0.0954
d	0.0293	SWE	3	0.0879
c	0.0244	ESW	3	0.0731
u	0.0218	SEN	3	0.0653
f	0.0203	ESNE	4	0.0812
m	0.0200	WSWN	4	0.0802
w	0.0176	WNWN	4	0.0706
y	0.0160	SWSE	4	0.0641
p	0.0155	WNEN	4	0.0620
g	0.0139	ESNS	4	0.0558
b	0.0129	SEW	3	0.0387
v	0.0077	WNWS	4	0.0308
k	0.0047	WSWE	4	0.0187
x	0.0015	SWSN	4	0.0061
j	0.0013	SESW	4	0.0051
q	0.0008	WSES	4	0.0032
z	0.0003	SWSW	4	0.0010
			KSPC =	3.0473

MDITIM *KSPC*

Character	*p*	MDITIM Code	Code Length	*p* x length
_	0.1843	NE	2	0.3685
e	0.1028	WES	3	0.3083
t	0.0778	SNE	3	0.2334
a	0.0661	NSW	3	0.1982
o	0.0629	WSEN	4	0.2518
i	0.0592	WNS	3	0.1775
n	0.0580	NSN	3	0.1741
s	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0.0013	SESW	[illegible]	[illegible]
q	0.0008	WSES	4	0.0032
z	0.0003	SWSW	4	0.0010
			KSPC =	3.0473

MDITIM *KSPC*

Character	*p*	MDITIM Code	Code Length	*p* x length
_	0.1843	NE	2	0.3685
e	0.1028	WES	3	0.3083
t	0.0778	SNE	[illegible]	[illegible]
a	0.0661	NSW	[illegible]	[illegible]
o	0.0629	WSEN	[illegible]	[illegible]
i	0.0592	WNS	[illegible]	[illegible]
n	0.0580	NSN	[illegible]	[illegible]
s	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0.0013	SESW	[illegible]	[illegible]
q	0.0008	WSES	4	[illegible]032
z	0.0003	SWSW	4	0[illegible]10
			KSPC =	3.0473

Can reduce *KSPC* further (by 50%) using…

Minimum Redundancy Code[1]

A Method for the Construction of Minimum-Redundancy Codes*

DAVID A. HUFFMAN+, ASSOCIATE, IRE

Summary—An optimum method of coding an ensemble of messages consisting of a finite number of members is developed. A minimum-redundancy code is one constructed in such a way that the average number of coding digits per message is minimized.

Introduction

ONE IMPORTANT METHOD of transmitting messages is to transmit in their place sequences of symbols. If there are more messages which might be sent than there are kinds of symbols available, then some of the messages must use more than one symbol. If it is assumed that each symbol requires the same time for transmission, then the tim...

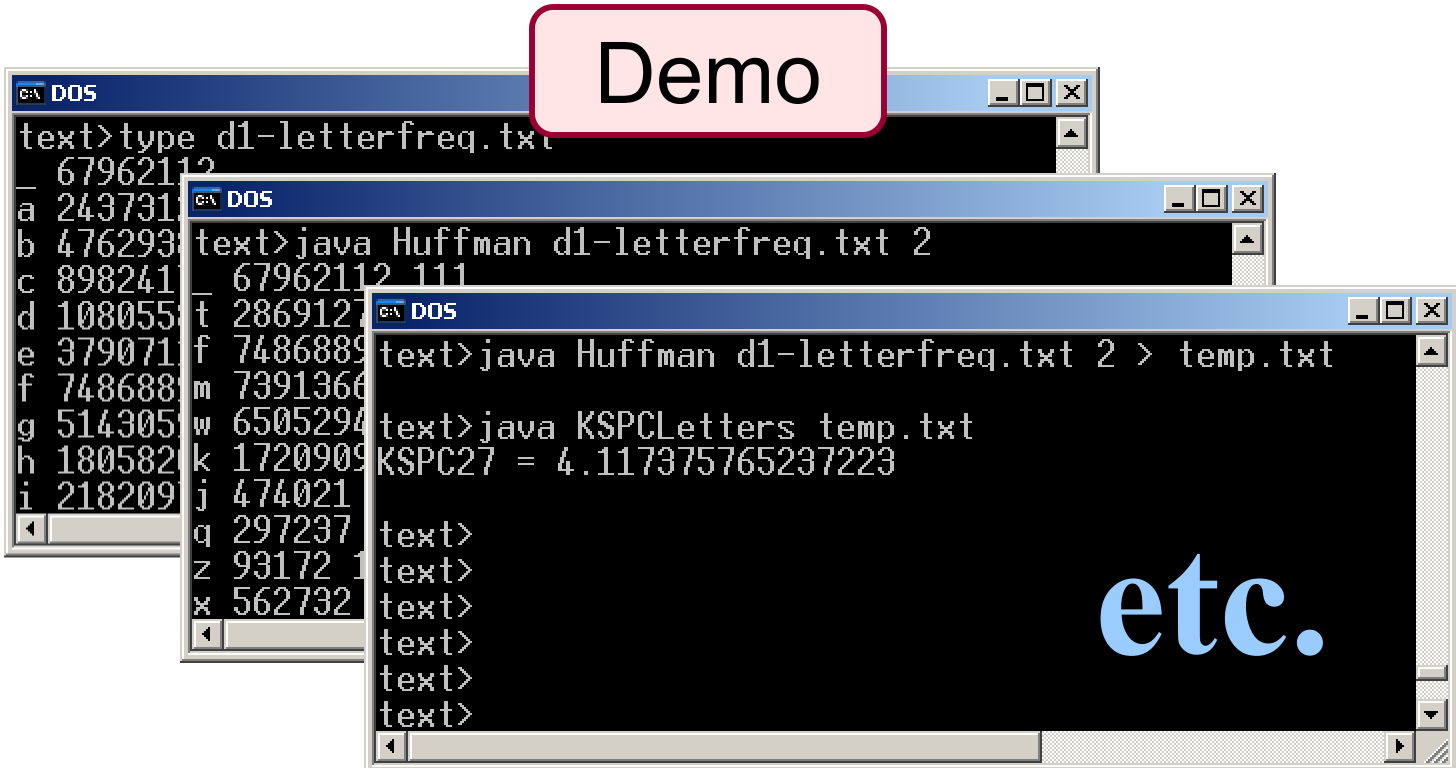
...will be defined here as an ensemble code which, for a message ensemble consisting of a finite number of members, N, and for a given number of coding digits, D, yields the lowest possible average message length. In order to avoid the use of the lengthy term "minimum-redundancy," this term will be replaced here by "optimum." It will be understood then that, in this paper, "optimum code" means "minimum-redundancy code."

The following basic restrictions will be imposed on an ensemble code:

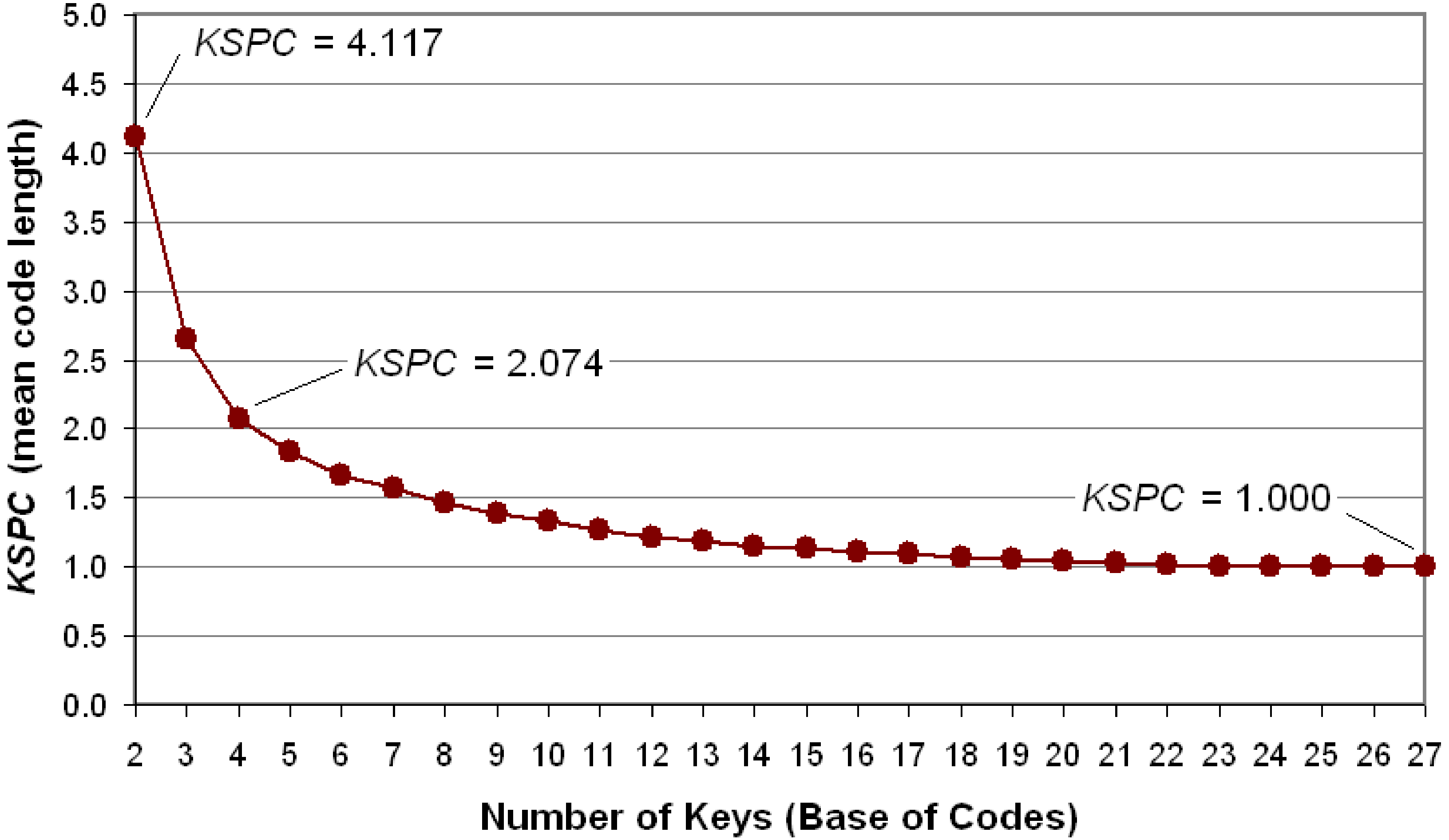
(a) No two messages will consist of identical arrangements of coding digits.

[1] Huffman, D. A. (1952). A method for the construction of minimum redundancy codes. *Proceedings of the IRE, 40*, 1098-1101.

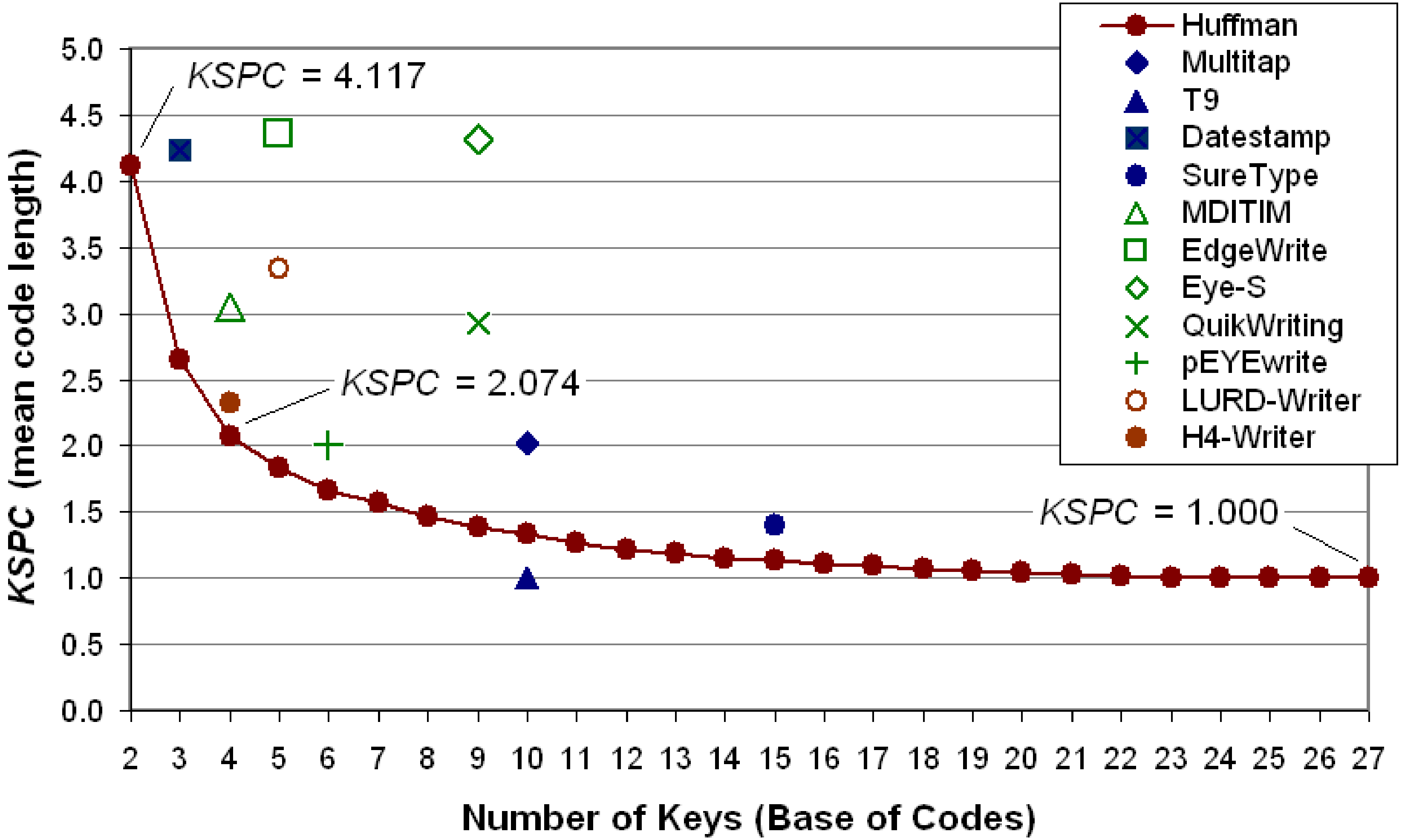
Huffman Codes & *KSPC*



Huffman *KSPC* vs. Number of Keys



Huffman *KSPC* vs. Number of Keys



Sidebar

Information (H) and $KSPC$

SKIP

DOS

```
_ 67962112 111
t 28691274 1101
f 7486889 110011
m 7391366 110010
w 6505294 110001
k 1720909 11000011
j 474021 1100001011
q 297237 11000010101
z 93172 11000010100
x 562732 110000100
v 2835696 1100000
a 24373121 1011
l 11730498 10101
y 5910495 101001
p 5719422 101000
o 23215532 1001
i 21820970 1000
n 21402466 0111
d 10805580 01101
g 5143059 011001
b 4762938 011000
e 37907119 010
s 19059775 0011
h 18058207 0010
r 17897352 0001
c 8982417 00001
u 8022379 00000
```

$$H = -\sum \left(P_i \times \log_2 P_i \right)^{1} = 4.081 \text{ bits}$$

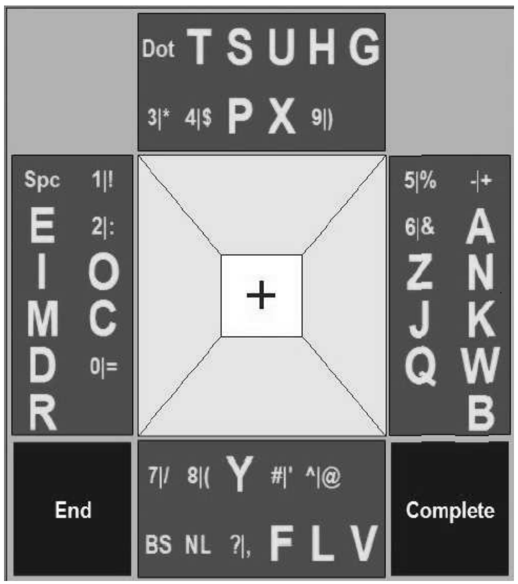
?

$$KSPC = \frac{\sum \left(K_i \times F_i \right)}{\sum \left(C_i \times F_i \right)} = 4.117$$

$\log_2(27) = 4.755$

[1] Shannon, C. E. (1951). Prediction and entropy of printed English. *Bell System Technical Journal, 30*, 51-64.

LURD-Writer *KSPC*



Character	*p*	LURD-Writer Code	length	*p* x length
_	0.1843	L*	2	0.3685
e	0.1028	LL*	3	0.3083
t	0.0778	UU*	3	0.2334
a	0.0661	RR*	3	0.1982
o	0.0629	LUUR*	5	0.3147
i	0.0592	LU*	3	0.1775
n	0.0580	RD*	3	0.1741
s	0.0517	UR*	3	0.1550
h	0.0490	URR*	4	0.1958
r	0.0485	LUR*	4	0.1941
l	0.0318	DLL*	4	0.1272
d	0.0293	LUU*	4	0.1172
c	0.0244	LURR*	5	0.1218
u	0.0218	UUR*	4	0.0870
f	0.0203	DDL*	4	0.0812
m	0.0200	LLU*	4	0.0802
w	0.0176	RDD*	4	0.0706
y	0.0160	DLLU*	5	0.0801
p	0.0155	URRD*	5	0.0775
g	0.0139	URD*	4	0.0558
b	0.0129	RDL*	4	0.0517
v	0.0077	DLU*	4	0.0308
k	0.0047	RRD*	4	0.0187
x	0.0015	URDD*	5	0.0076
j	0.0013	RDLL*	5	0.0064
q	0.0008	RDLU*	5	0.0040
z	0.0003	RDDL*	5	0.0013
			KSPC =	3.3387

LURD-Writer *KSPC*

Character	*p*	LURD-Writer Code	length	*p* x length
_	0.1843	L*	2	0.3685
e	0.1028	LL*	3	0.3083
t	0.0778	UU*	3	0.2334
a	0.0661	RR*	3	0.1982
o	0.0629	LUUR*	5	0.3147
i	0.0592	LU*	3	0.1775
n	0.0580	RD*	3	0.1741
s	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible].0013	RDLL[illegible]	[illegible]	[illegible]
q	0.0008	RDLU*	5	0.0040
z	0.0003	RDDL*	5	0.0013
* = delimiter			*KSPC* =	3.3387

H4-Writer[1]

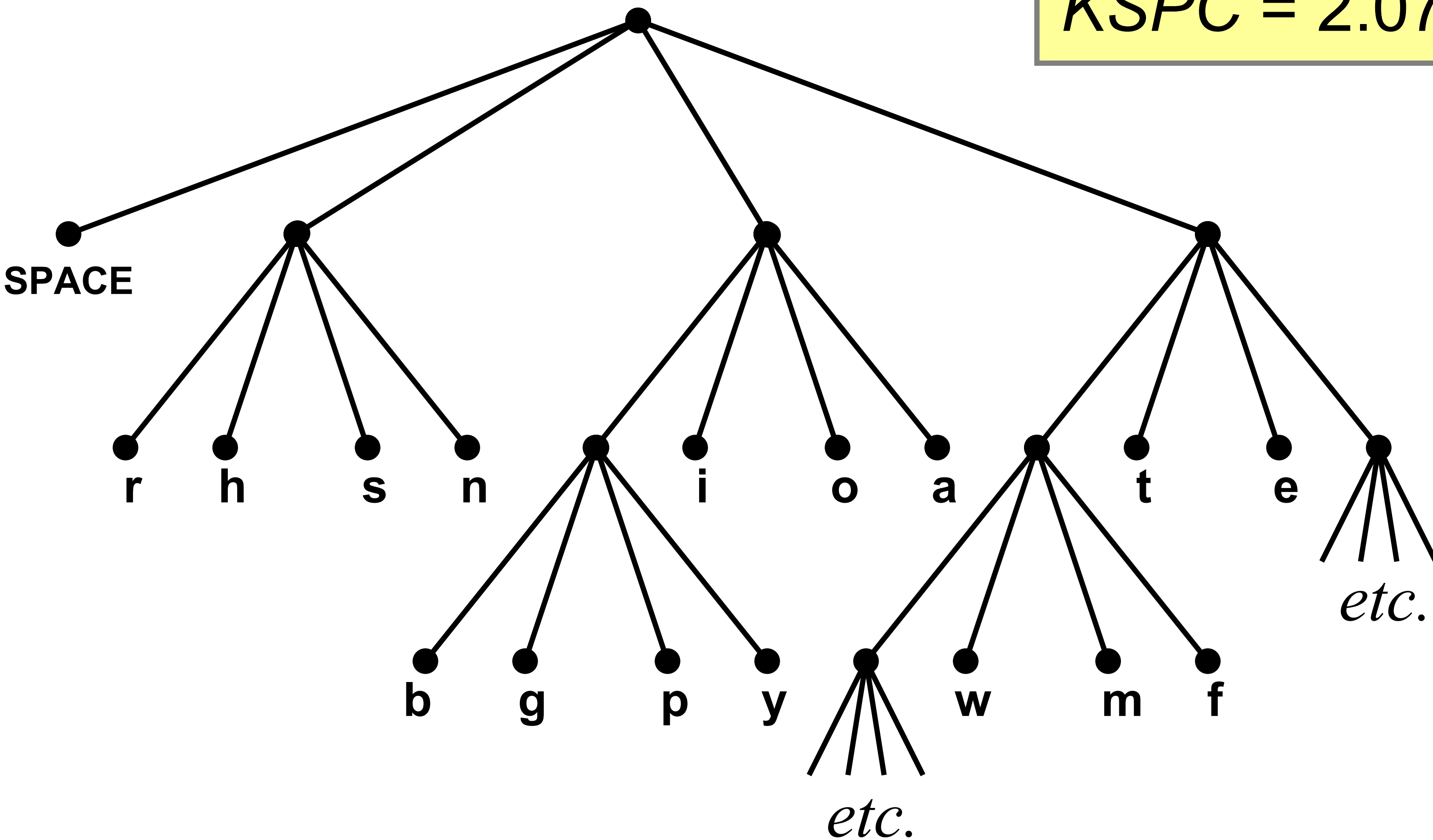
- Huffman code assignments for LURD-Writer
- *KSPC* = 2.074, but…
- One top leaf-node "removed", used for…
  - Backspace, Enter
  - Caps, CapsLock
  - Digits (0 1 2 3 4 5 6 7 8 9)
  - Punctuation (. , ? ' " ! ; : ! @ $ % 6 & …)
  - Etc.

  Manual assignments
- *KSPC* = 2.322 (access to all symbols, modes, etc)

[1] MacKenzie et al. (work in progress)

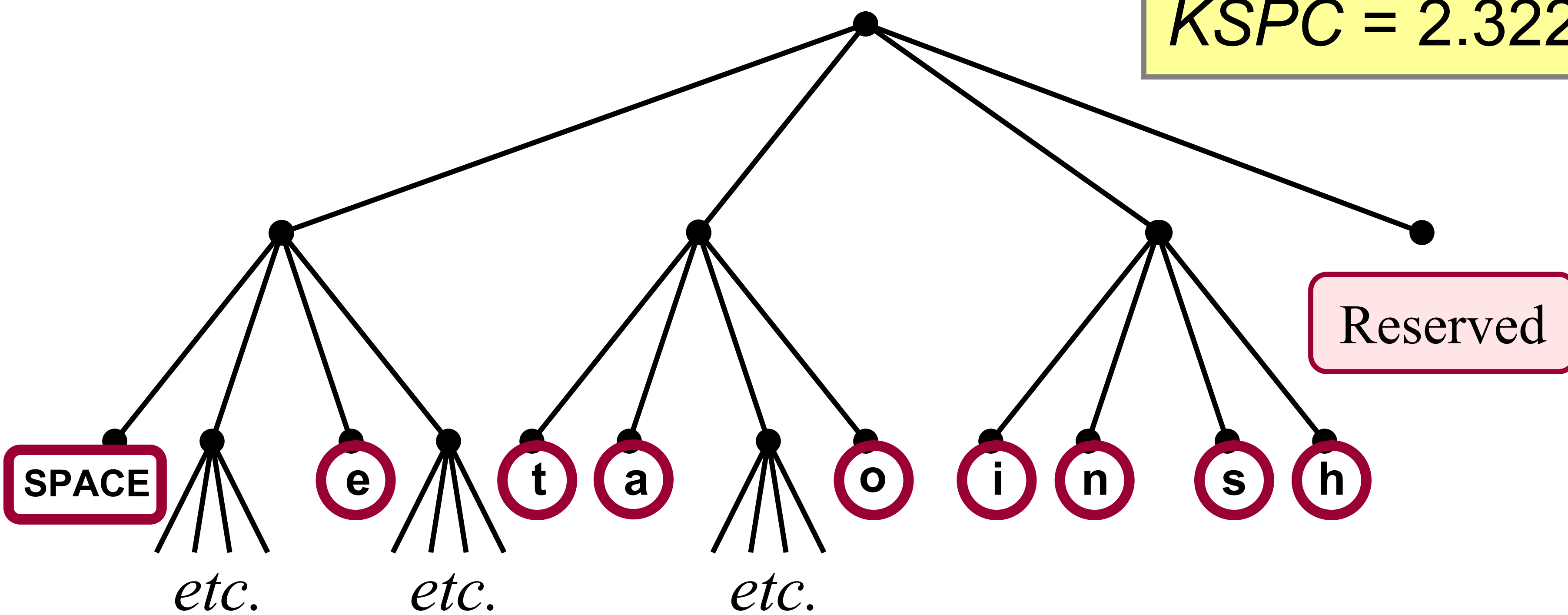
Huffman Base 4 Tree

KSPC = 2.074



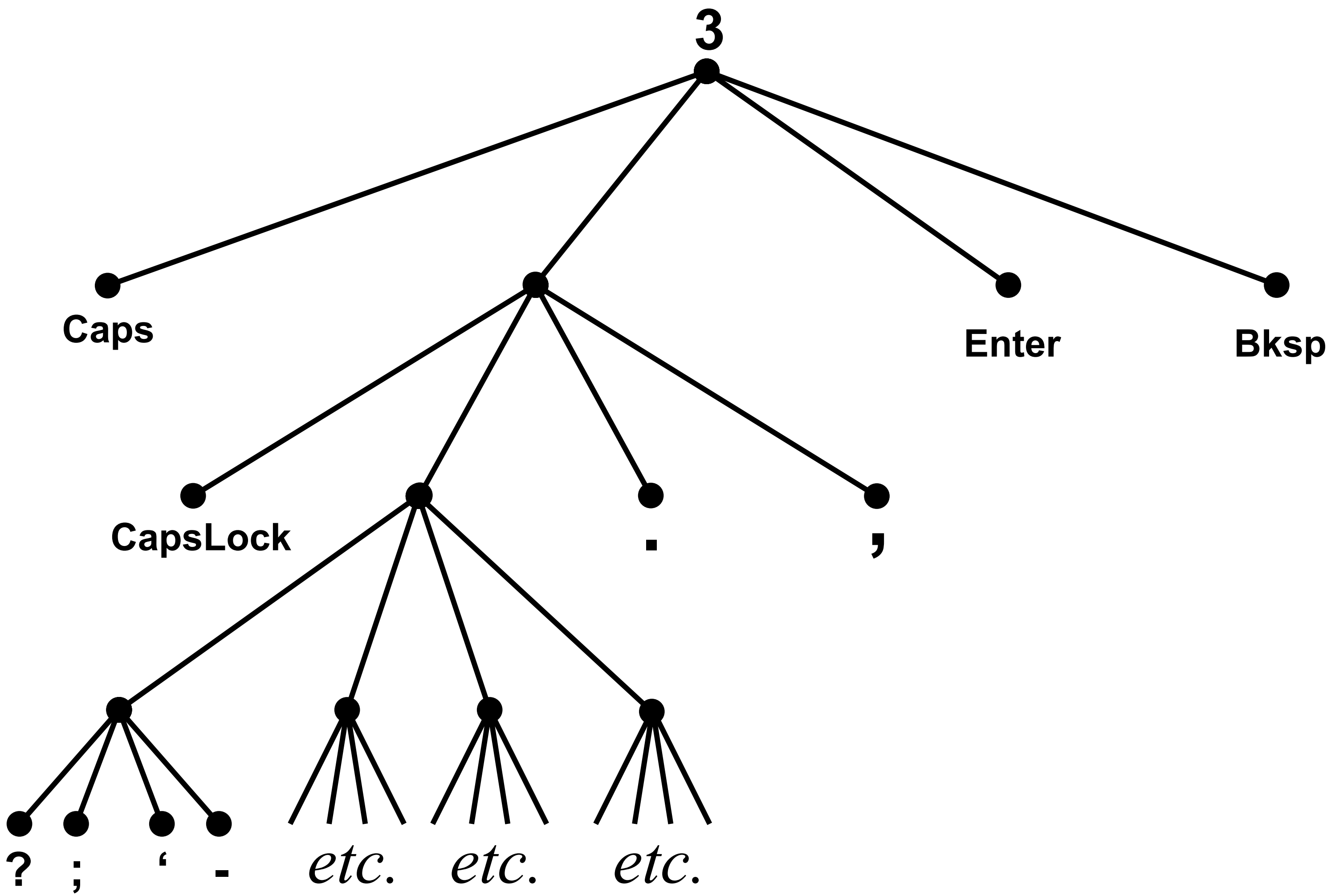
H4-Writer Tree

KSPC = 2.322



Top 9 symbols @ *KSPC* = 2.0 (71.2% of English)

H4-Writer "Reserved" Tree



H4 Codes

Symbol	Code
[SPACE]	LL
a	UU
b	LURL
c	LDL
d	LUD
e	LR
f	LDR
g	URD
h	RD
i	RL
j	LURDU
k	LURR
l	LUU
m	LDD
n	RU
o	UD
p	URR

Symbol	Code
q	LURDRL
r	LUL
s	RR
t	UL
u	LDU
v	LURU
w	URL
x	LURDL
y	URU
z	LURDRU
Bksp	DD
Enter	DR
Caps	DL
CapsLock	DUL
.	DUU
,	DUR
[more]	DUD

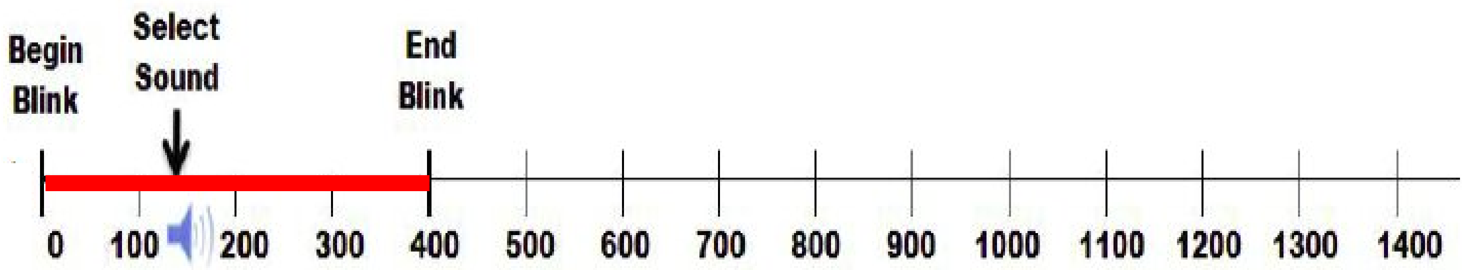
UI Heuristics

- Repeating codes (e.g., “a” = UU)
  - Keyed input ✓
  - Gestural input ✗ (✓dwell time + audio feedback)

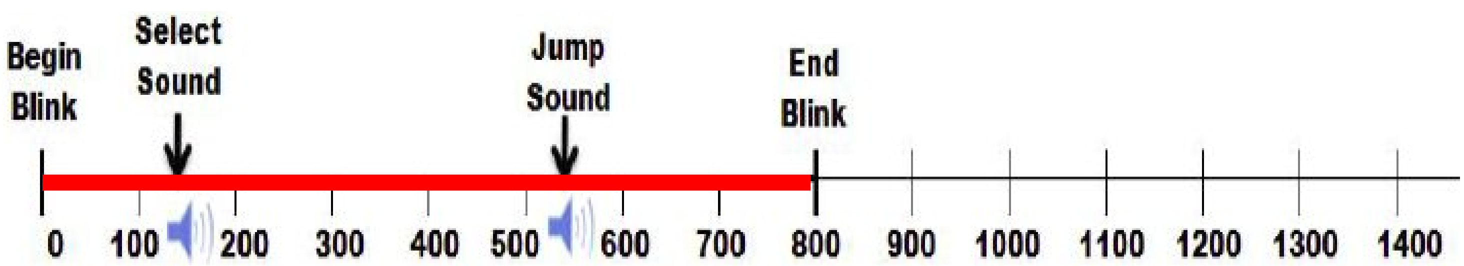
SHOW

- Learning and retention
  - Gesture shape vs. code length
- Reserved code-tree branches for custom designs

… from *BlinkWrite2*



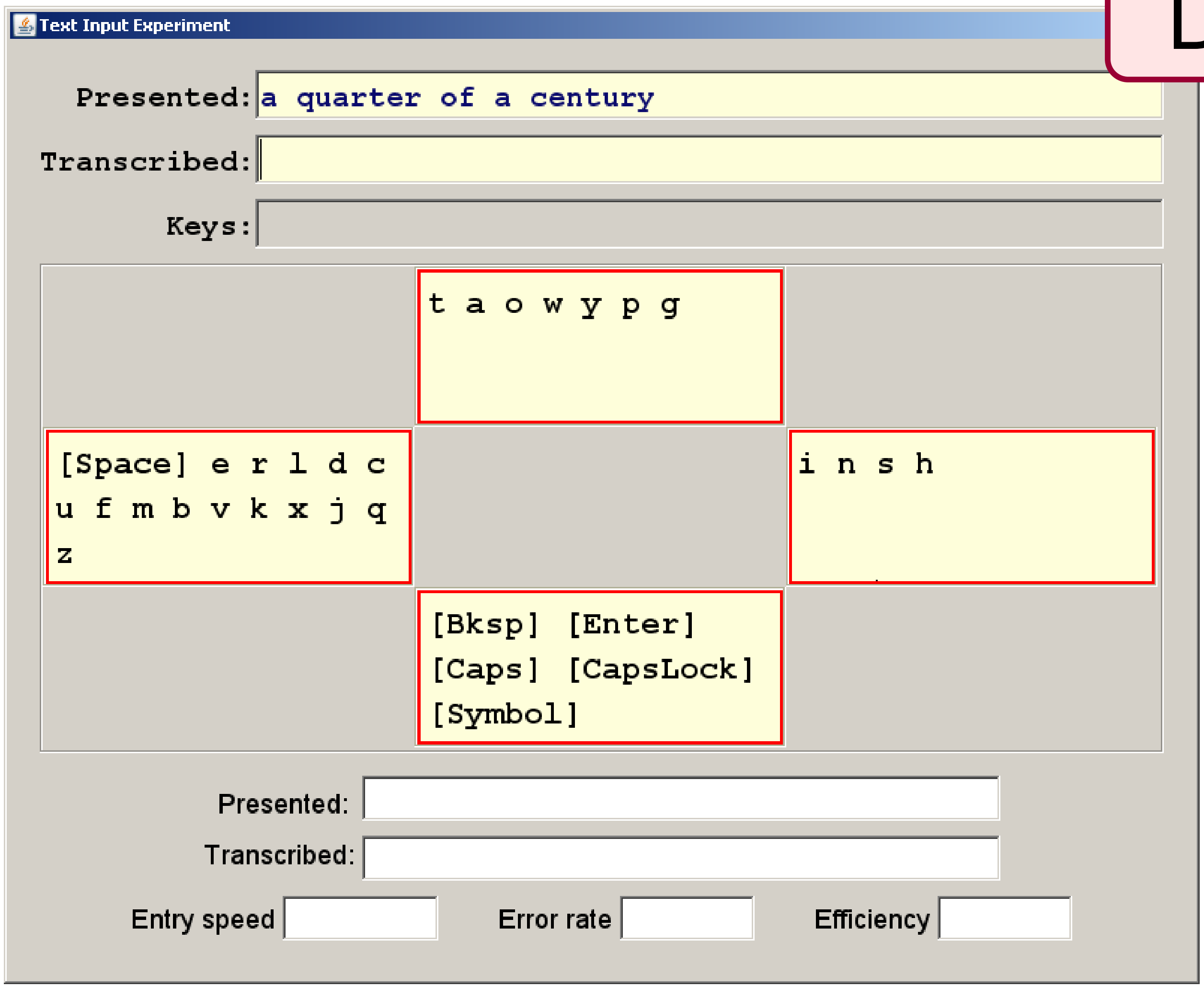
150 ms to 550 ms → "click"



550 ms to 1200 ms → "click" "click"

H4-Writer

Demo



H4-Writer Input Possibilities

Relative

✗

Relative

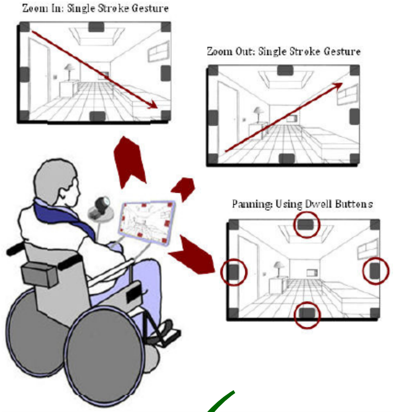
✗

Relative

✗

✓

✓



✓

✓

H4-Writer Feedback

RDRLLUULULLUUUDLLURLUDLULLUUULUDDR

h e l r l o _ w o r l d ¬

Legend
Click sound
Typewriter key sound
Typewriter return sound

Wrap-up

- An eye on input
  - Characteristics of the eye (saccades, fixations, fovea "region of uncertainty", etc.)
  - Looking
  - Selecting
  - Evaluating
- Eye gestures for text input
- H4-Writer (work in progress)
- BlinkWrite2 (…Wednesday)

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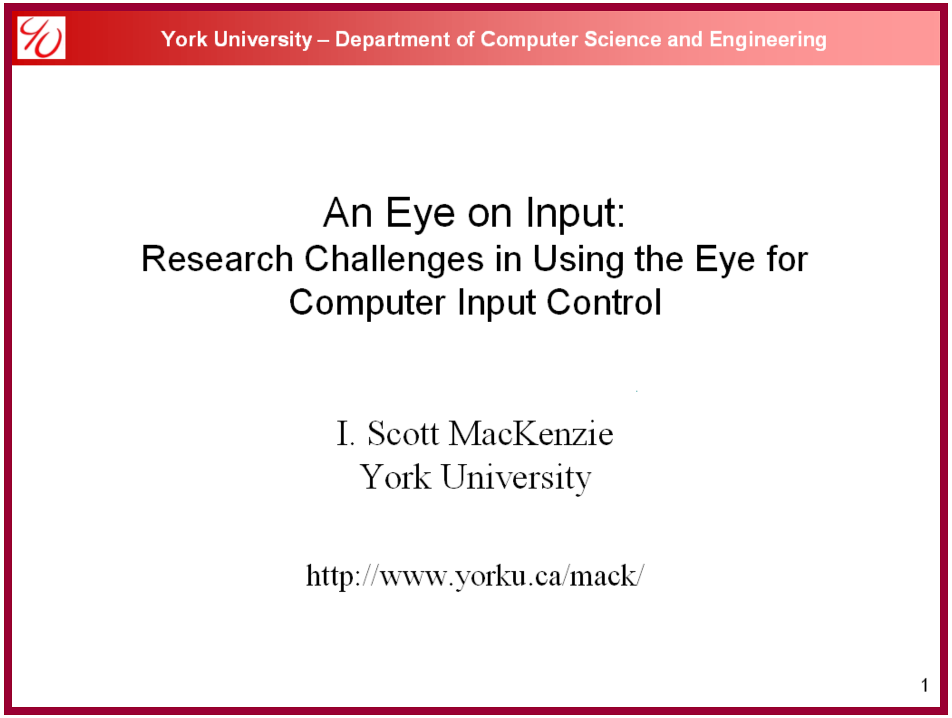
De Montfort University University of Tampere

Thank You – Questions?



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11. Zhang, X., Ren, X., and Zha, H., Improving eye cursor's stability for eye pointing tasks,,, Proceedings of the ACM Conference on Human Factors in Computing Systems - CHI 2008. Florence, Italy: New York:ACM, 2008, 525-534.