

# New Approaches to Hardware and Software for Bimanual Computer Interfacing



# The Research Question

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How can bimanual interfacing make computer interfacing more intuitive, efficient, and comfortable?

This question is important because of existing interface's deficiencies in these areas:

- **Non-Intuitive** - Motions and manipulations that are natural to us in physical space are impossible on the computer.
- **Time-Inefficient** – Requiring extra cursor and arm movements between input devices and between workspace and toolbars/menus
- **Repetitive Strain Injuries (RSIs)** – In 2002, Gerr et. al. found that jobs requiring >15 computer use hours/week resulted in more than 50% of subjects reporting musculoskeletal symptoms in the first year.

# Why Bimanual Computer Interfacing?

Bimanual Computer Interfacing is simply the simultaneous use of two hands to enable **continuous** input. It can address several key aspects of the research question.

## Intuitive

- **Enabling more input methods** – providing manipulations that are more natural, with more degrees of freedom.
- **Enabling more sensory feedback** – such as the use of proprioception.

## Time Efficient

- **Facilitating parallel input** – reducing overall input time.

## Comfortable

- **Splitting work loads between two limbs** – reducing the load on a single limb.
- **Providing new body positions and motions for input** – potentially improving comfort

# Need for Hardware and Software

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Fully addressing the research question requires investigating an integrated hardware/software platform.

**Hardware** Enables bimanual input

**Intuitiveness:** provide natural manipulation motions, DOFs

**Efficiency:** pointing speed, homing time, accuracy

**Comfort:** physical interface must follow ergonomic concepts

**Software** Accepts and implements bimanual input

**Intuitiveness:** maintain virtual analogues of natural physical manipulations

**Efficiency:** reduce need for pointer motions

**Comfort:** efficient design reduces repetitious motions and clicks

# Road Map

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How can bimanual interfacing make computer interfacing more intuitive, efficient, and comfortable?

## Software

- ➔ 1) Investigate appropriate virtual analogues of physical manipulations
- 2) Identify/create candidate input methods within promising metaphors
- 3) Test and compare input methods
- 4) Implement most effective input methods into a usable system

## Hardware

- 1) Identify areas where pointing device improvements may be made
- 2) Implement improvement concepts in new pointing system
- 3) Test pointing system

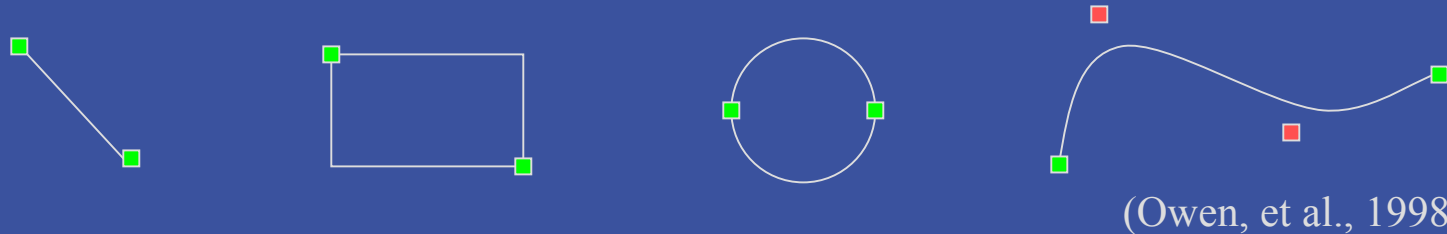
# Bimanual Metaphors - Independent

Concept: Dominant Hand (DH) and Non-Dominant Hand (NDH) move independently of each other

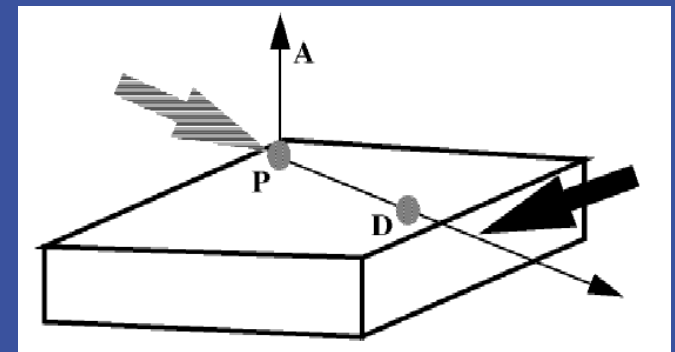
How can we apply this metaphor in a virtual environment?

**Two cursors?:** This approach has been shown to be slower than unimanual approach due to an increase in cognitive load. (*Kabbash, et al. – 1994*)

It can provide new ways to manipulate virtual objects - such as specifying shapes (lines, rectangles, etc.) through two control points simultaneously



This approach may also be useful for manipulating multiple virtual objects simultaneously. This is potentially useful for virtual assembly.



# Bimanual Metaphors – Kinematic Chain

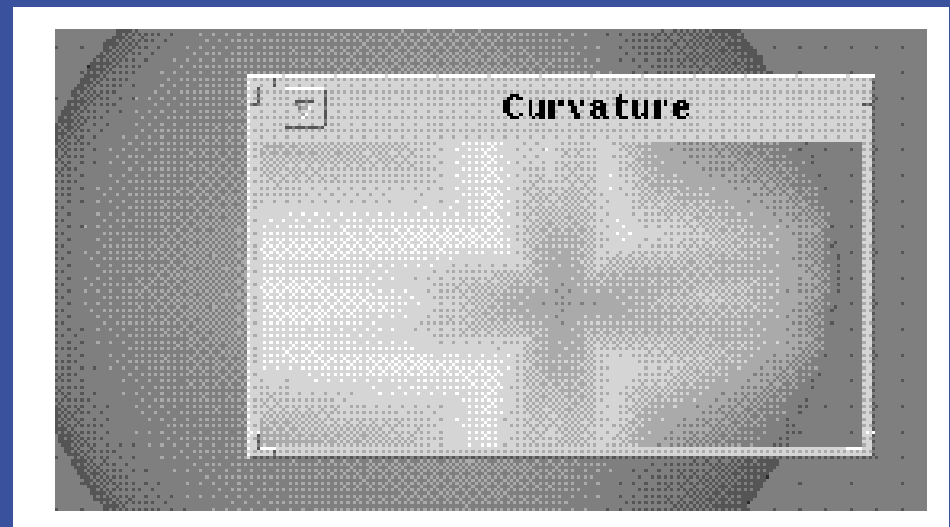
Concept: NDH sets frame of reference for DH, NDH moves first, NDH provides a courser, slower motion.

- **Basis:** Guiard found that handwriting speed is reduced by 20% if users are not allowed to use their NDH to position the paper.

How can we apply this metaphor in a virtual environment?

**Magic Lenses:** Used to change display of visual information.

**Camera Positioning:** Pan, Zoom, Rotate



Guiard, Y., "Asymmetric Division of Labor in Human Skilled Bimanual Action: The Kinematic Chain as a Model," *The Journal of Motor Behavior*, 19 (4), 1987, pp. 486-517.

Figure from: Bier, E. A., Stone, M., Pier, K., Buxton, W. & DeRose, T. (1993). *Toolglass and magic lenses: the see-through interface*. Proceedings of SIGGRAPH '93, 73-80

# Bimanual Metaphors— Object/Command

Concept: DH specifies the object (or the noun), and the NDH specifies the command (or verb). (E.g. hammer this nail, staple these papers )

How can we apply this metaphor in a virtual environment?

The simplest example is the use of **hotkeys** in standard interfacing. This increases parallel activity, and reduces required pointer motions.



Object/Command has been previously implemented, but never before described as a general metaphorical approach to bimanual interfacing.

Object/Command is the  
Metaphor implemented in  
AmbiCAD GL.

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# Bimanual Software - AmbiCAD GL

I created a simple drawing program to examine several methods of implementing the object/command metaphor of bimanual interfacing.

## Task:

Users must draw shapes from scratch to match a given target shape.

## Reference Testing Methods:

Standard Toolbar (TB)

Standard Marking Menus (MM)

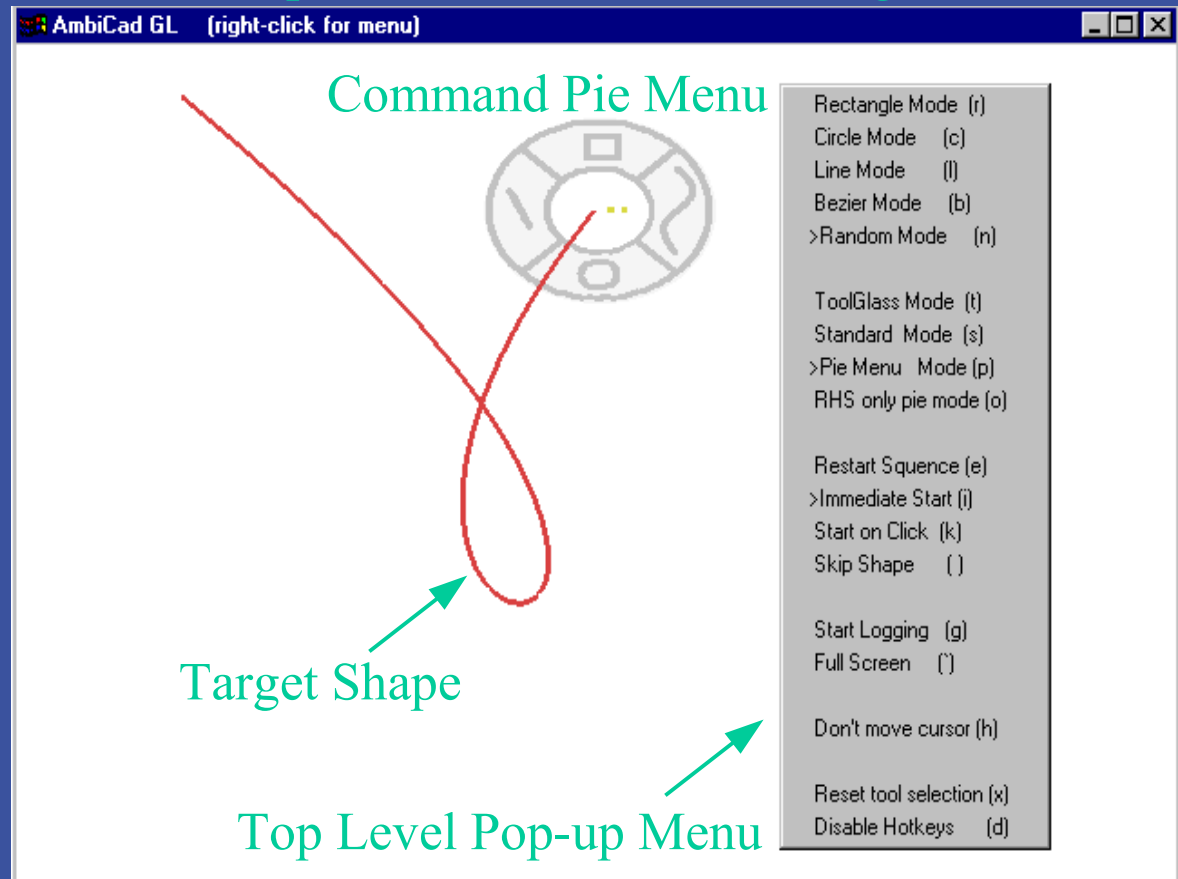
## Bi-Manual Testing Methods:

Toolglass (TG)

Hot Keys Mapped (HKM)

Hot Keys Grouped (HKG)

\* Bimanual Marking Menus (BMM)



AmbiCAD Demo

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# AmbiCAD GL: Experimental Design

AmbiCAD GL has been designed to record:

- 1) Completion time
- 2) Number of button clicks required to perform each operation.

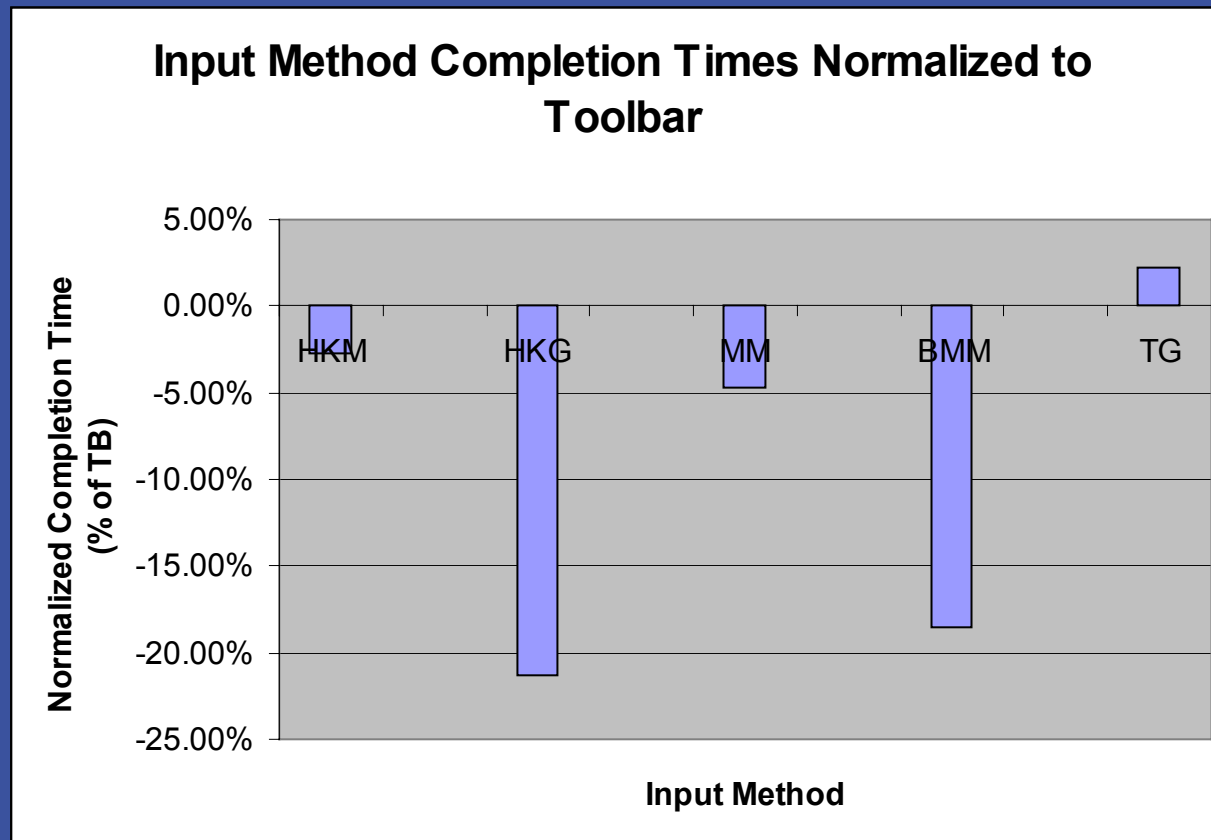
## Independent Variables

- User – 10 subjects
- Mode – TB, HKG, HKM, MM, BMM, TG
- Shape – Line, Rectangle, Ellipse
- Shape Position – Close to home, far from home
- Shape Size – Large, Small
- Block Number – 1 to 8
- Repetitions – 2

## Null Hypotheses

- H1 – There is no difference in **average completion time** between input methods. (Efficiency)
- H2 – There is no difference in **learning rate** between input methods. (Intuitiveness)
- H3 – There is no difference in **error rate** between input methods. (Efficiency)

# Toolbar Normalized Completion Time



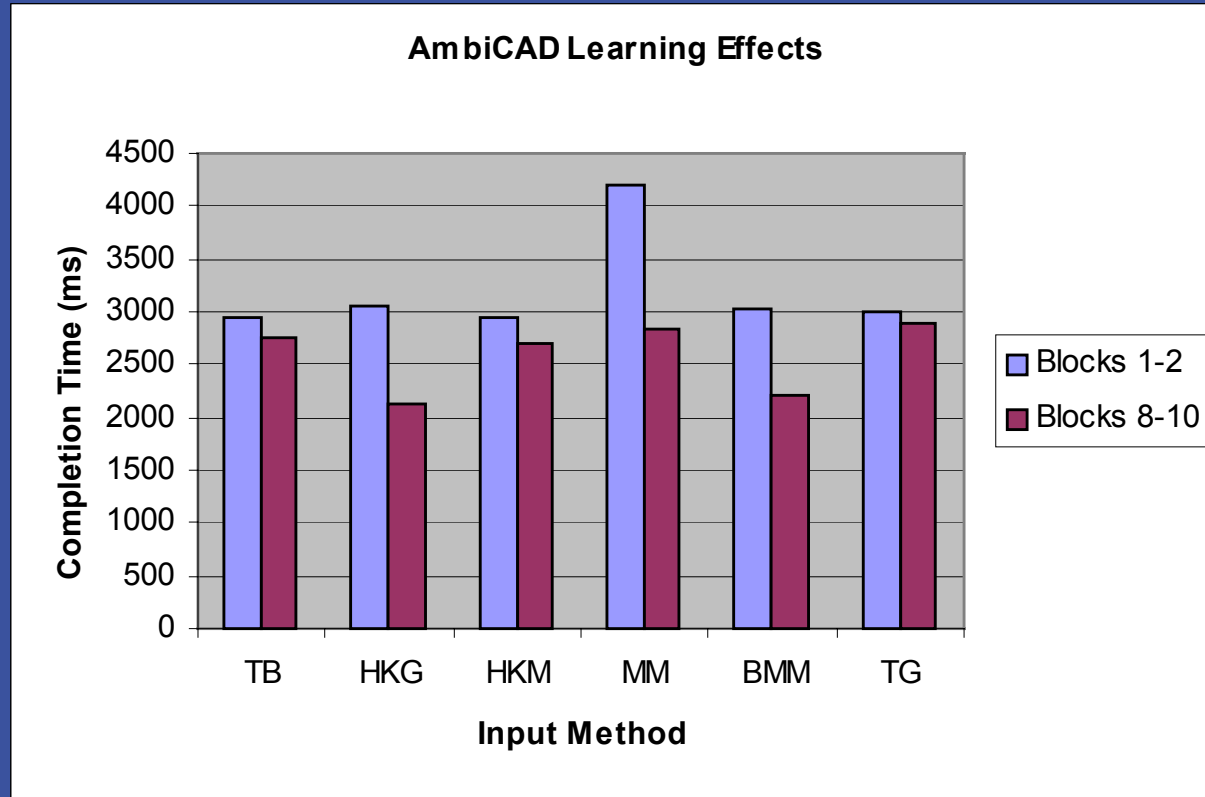
Faster is Better



**Novel Approach of Bi-manual Marking Menus 2<sup>nd</sup> fastest overall!**

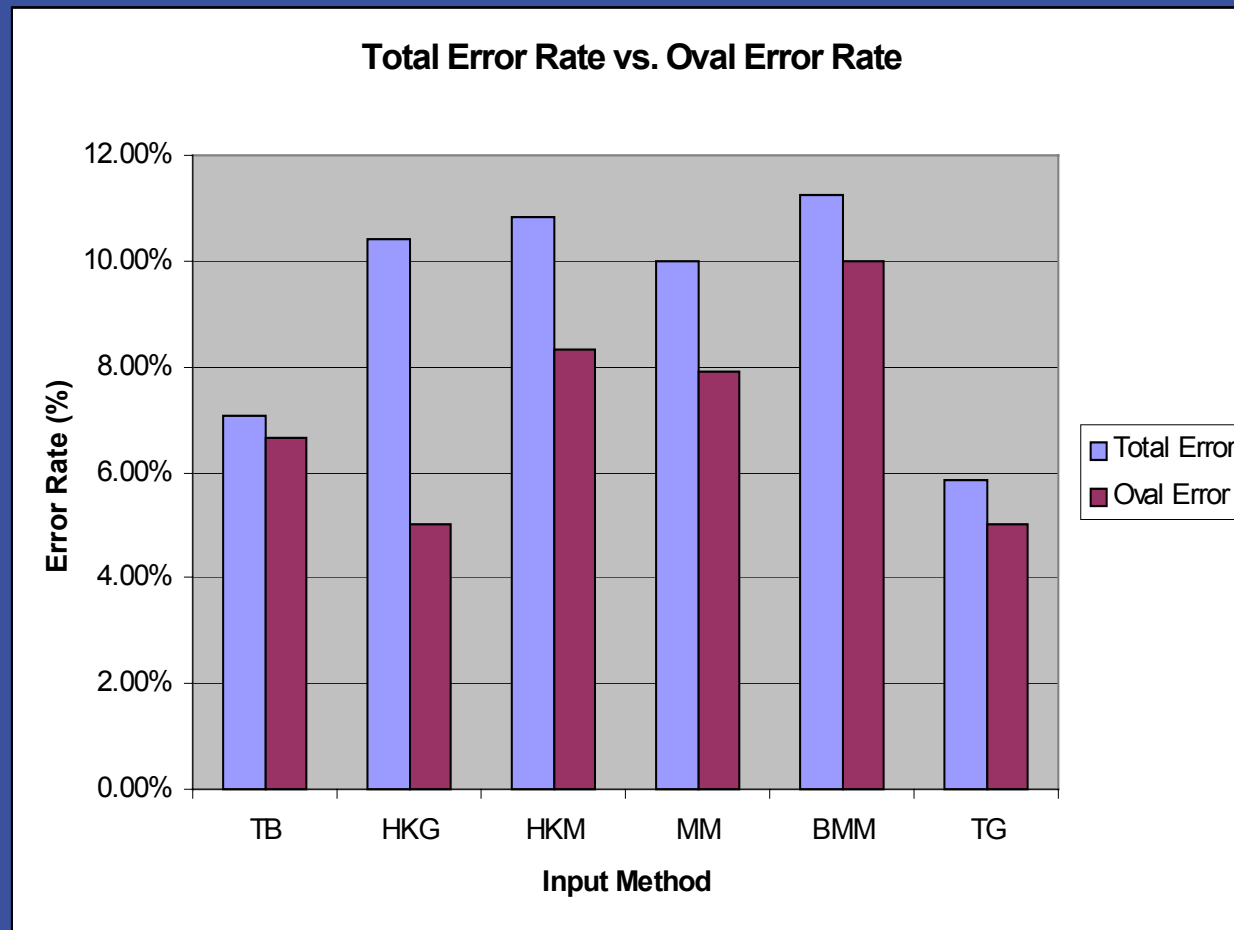
Other Benefits: no dedicated keys, extra DOFs can be used for other purposes, doesn't clutter workspace, beginning/advanced transition.

# AmbiCAD – Learning Effects



Method	TB	HKG	HKM	MM	BMM	TG
% Improvement	6.3%	30.4%	9.2%	32.8%	26.7%	4.0%

# Practiced Performance – Error Rate



Oval Errors accounted for ~80% of total error!

HKG has highest rate of input error.

TG has lowest overall error rate.

# AmbiCAD Subjective Feedback

2-hand marking menus just seemed fast and efficient

I don't think grouped hotkeys would scale

Grouped Hotkeys is very fast

One-handed inputs were most comfortable physically

Preference Ranking (6=best)	Input Method
6	BMM
5	HKG
4	TB
3	MM
2	TG
1	HKM

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# Current Input Device Shortcomings

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Several areas of today's standard input devices are worth addressing in the development of new devices.

**Homing time** due to switching between input devices

**Repetitive Strain Injuries** – many ergonomic problems with standard mouse and keyboard

**Crowding** of ideal working space – multiple input devices to occupy it

**Inflexible** workstation setup due to disconnect between user's chair and desk

**Bimanual devices must also:**

Maintain natural mapping between physical and virtual environments

Provide continuous input from both hands

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# The Command Chair

The Command Chair is a custom built bimanual input device, which represents a configurable platform for experimentation with bimanual and ergonomic concepts.

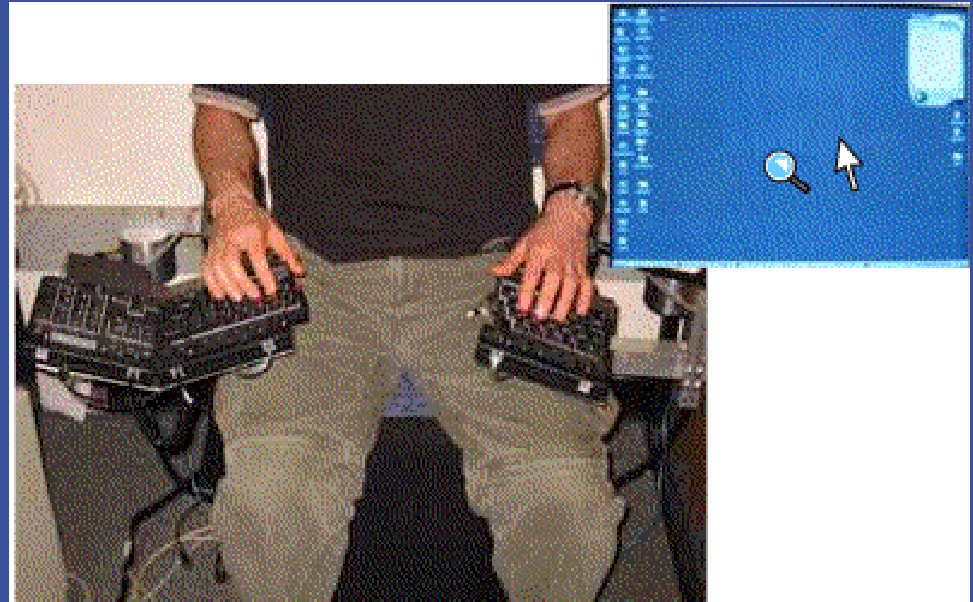
## It Consists of:

Two freely moving articulated armrests

Keyboard half at end of each arm with integrated mouse buttons

Armrest motion serves as the pointer input

It addresses crowding, homing time, and inflexibility issues through the integration of chair, mouse, and keyboard.



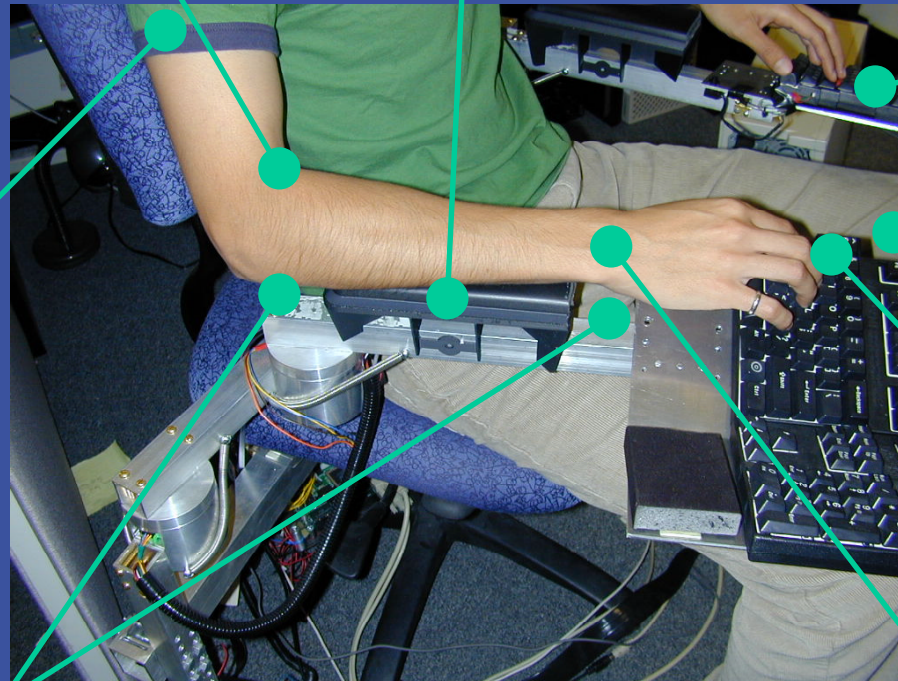
# Command Chair Ergonomic Concepts

Interior elbow angle  
> 121° (Marcus, et al., 2002)

Lower arm support  
(Marcus, et al., 2002,  
Feng, et al. 1997)

Reduced repetition  
through bimanual  
input (Marcus, et al., 2002)

Actuated by  
upper arm (CSA-  
Z412-M89)



Elbow higher than  
“J” key (Marcus, et al., 2002)

Low contact pressure  
on elbow and wrist  
(Tichauer, et al. 1966)

Neutral wrist  
position (Bach, et al.  
1997)

# The Command Chair - Mappings

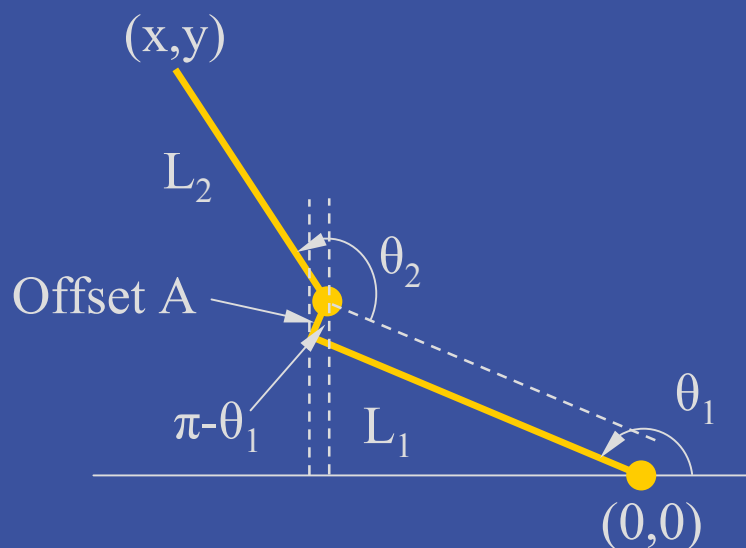
## Kinematic Mapping

## Direct Mapping

2<sup>nd</sup> Joint Motion



Cursor Motion



Presume:  
Small Angles  
Human Visual Feedback  
compensates for approximation

$$X = L1 * \cos(\theta_1) + L2 * \cos(\theta_2 + \theta_1 - \pi) - A * \sin(\pi - \theta_1)$$

$$\Delta X = L_2 * \Delta \theta_2$$

$$Y = L1 * \sin(\theta_1) + L2 * \sin(\theta_2 + \theta_1 - \pi) - A * \cos(\pi - \theta_1)$$

$$\Delta Y = L_1 * \Delta \theta_1$$

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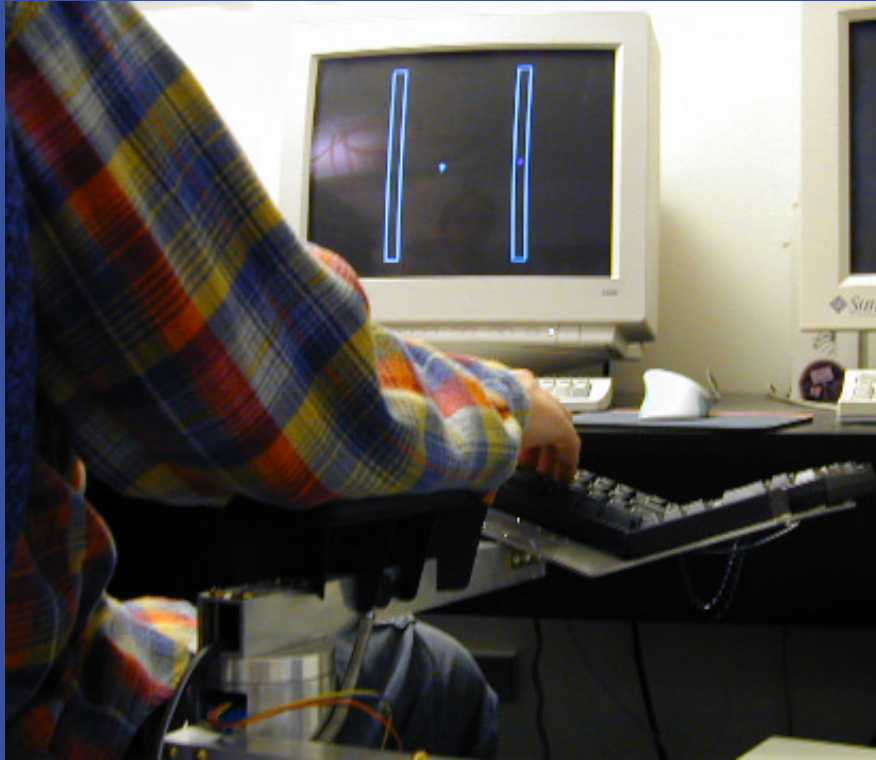
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# 1-D Tapping Test: Experimental Design



## Hypotheses

- H1 – The CC is **slower** than the mouse.
- H2 – The Direct CC mapping shows the highest **learning rates**.
- H3 – There is no difference in **error rates** between pointing devices.

**Goal:** Tap virtual targets, while GFLMB software measures:

- 1) Movement time
- 2) Error state
- 3) Tap location

## Independent Variables

Distance (80mm, 160mm, 320mm)

Width (4mm, 8mm, 16mm)

Reps. (4)

Block # (1-10)

Device (Mouse, Command Chair, Directly Mapped Command Chair)

User (1-10)

Testing designed to be in accordance with ISO 9241-9

# Practiced Pointing Performance

Fitts' law predicts the time required to tap between two targets.

$$MT = a + b \log_2(A/We + 1) \quad (\text{Shannon Formulation})$$

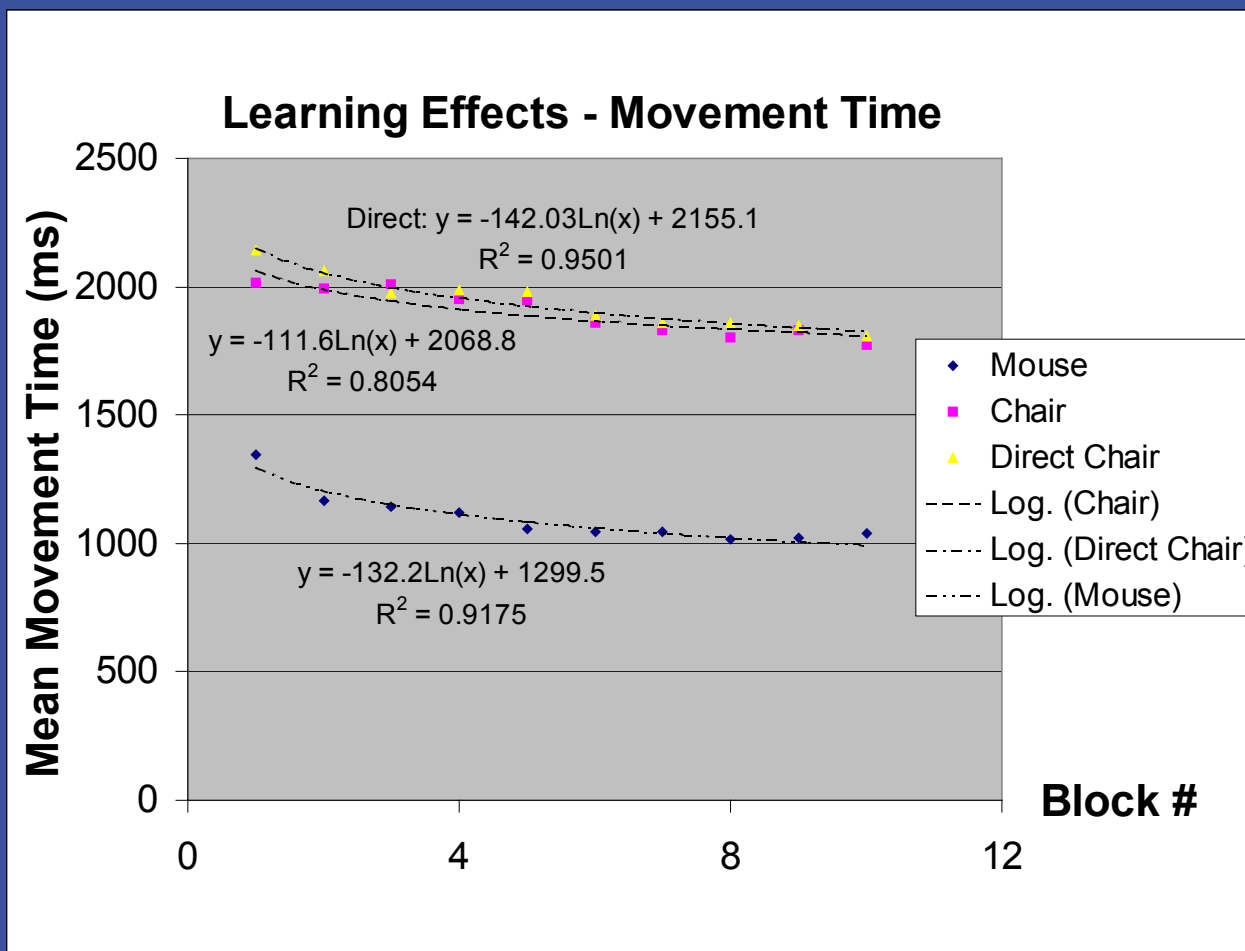
MT: Movement Time, a and b: Fitts' Constants, A: Amplitude, We: Effective Width

Index of Difficulty (ID) =  $\log_2(A/We + 1)$  measured in "bits"

$$\text{Throughput} = ID/MT$$

Device	Average Time	Throughput	Error Rate	4mm Error
Command Chair	1812 ms	2.56	3.80%	56% of total
Direct CC	1845 ms	2.54	3.43%	59% of total
Mouse	1026 ms	5.10	1.11%	41% of total
Significance	P<.0001	P<.0001	P=.0016	P=.0013

# Learning – Transient Effects



Device	Command Chair	Direct Chair	Mouse
Improvement ( $\Delta$ 1-2 vs. 8-10, ms)	241	288	250

ANOVA indicates a p=83% likelihood that learning rates are identical

# Command Chair Subjective Feedback

“Easy to learn” IV

“It’s comfortable. I can use it for a long time without fatigue”

“My muscles were tighter using the mouse and more relaxed when using the C. Chair.”

“Tiring to use.” II

“Fine movements were more difficult” IV

“[Kinematic mapping] was harder to control”

“I would overshoot several times.”

“I did have accuracy problems at extremities of the screen.”

“My arm muscles are not accustomed to precision pointing.”

## Subjective Questionnaire: Most Significant Results

Attribute	Chair vs. Mouse (1-5 Scale)
Accurate Pointing	-2.18
Shoulder Fatigue	+1.45
Wrist Fatigue	-1.45
Physical Effort	+1.36

# Conceptual Contributions

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- New classification of bimanual input metaphors (**Object/Command**).
- Invention of **Bimanual Marking Menus**.
- Testing of **Object/Command methods** for both one and two hands.
  - Intuitiveness: Learning Rates
  - Efficiency: Input Speed, Error Rates
  - Comfort: subjective

# System Contributions

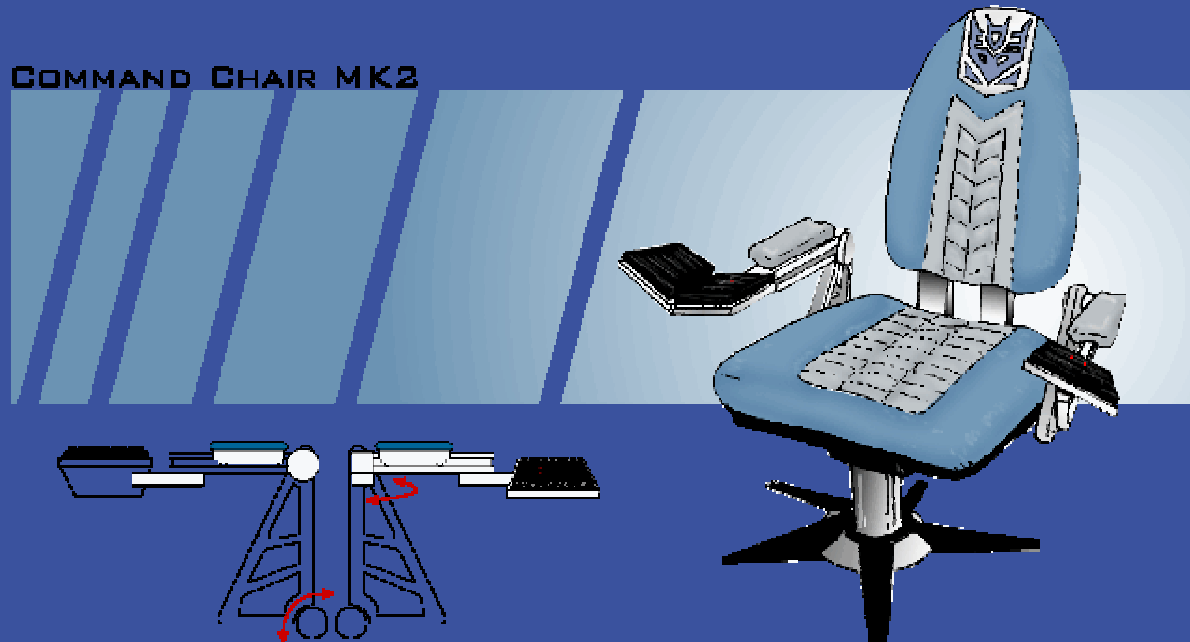
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- **Creation** of fully **integrated** computer input workstation (Chair/Mouse/Keyboard)
- **Development** of integrated bimanual interfacing **hardware/software platform**
- **Implementation** of **comfort design concepts** in workstation design
- **Testing** of Command Chair pointing
  - **Intuitiveness**: Learning Rates
  - **Efficiency**: Input Speed, Error Rates
  - **Comfort**: subjective and **future work**

# Future Work

- **Implementation** of **magnifying lens** as intro to bimanual concepts/benefits
- **Development** for open-source **graphical design environment** (GIMP) implementing lessons learned from testing, potentially including: bimanual marking menus, KC Theory (e.g. panning with NDH, pointing with DH), shape and object manipulation (e.g. bimanual spline manipulation)
- **Testing** effectiveness of **design for comfort**
- **Command Chair Mk2** – Reduce wiring and inertia, improve robustness, redesign around **user feedback**

COMMAND CHAIR MK2



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