

Looking Back: Fitts' Law

- Predicts movement time for rapid, aimed pointing tasks
- One of the few stable observations in HCI
- $MT = a + b \log_2 \left(1 + \frac{D}{W} \right)$ Index of Difficulty: $\log_2 \left(1 + \frac{D}{W} \right)$
- How to get a and b for a specific device / interaction technique
 - vary D and W and measure MT; fit a line by linear regression
- Various implications for HCI
 - Consider button sizes
 - Use edges and corners
 - Use current location of the cursor
 - Use average location of the cursor(?)
 - **Possibility to compare different input devices**

Looking Back: Steering Law

- Models the movement time of a pointer through a 2D tunnel
- Extension of Fitts' Law
- Tunnels with constant width: $MT = a + b \frac{D}{W}$ Index of Difficulty: D / W
- Extension for arbitrary tunnel shapes: $MT = a + b \int_c \frac{ds}{W(s)}$
- Implications for HCI
 - Nested menus
 - Navigation tasks
 - Extensions for virtual reality / 3D movements possible

Basic HCI Models

- Predictive Models for Interaction: Fitts' / Steering Law
- Descriptive Models for Interaction: GOMS / KLM

To Recap: *Predictive* Models

- Model:
 - Simplification of a complex situation / action, e.g. human interaction
- Predictive:
 - Make educated guesses about the future
 - » relying on knowledge about past actions / states
 - » relying on a model of interaction
- Examples:
 - Fitts' Law (directed aimed movement)
 - Law of Steering (navigation through a tunnel)
 - Hick's Law / Hick-Hyman Law (choose an item within a menu)
 - ...

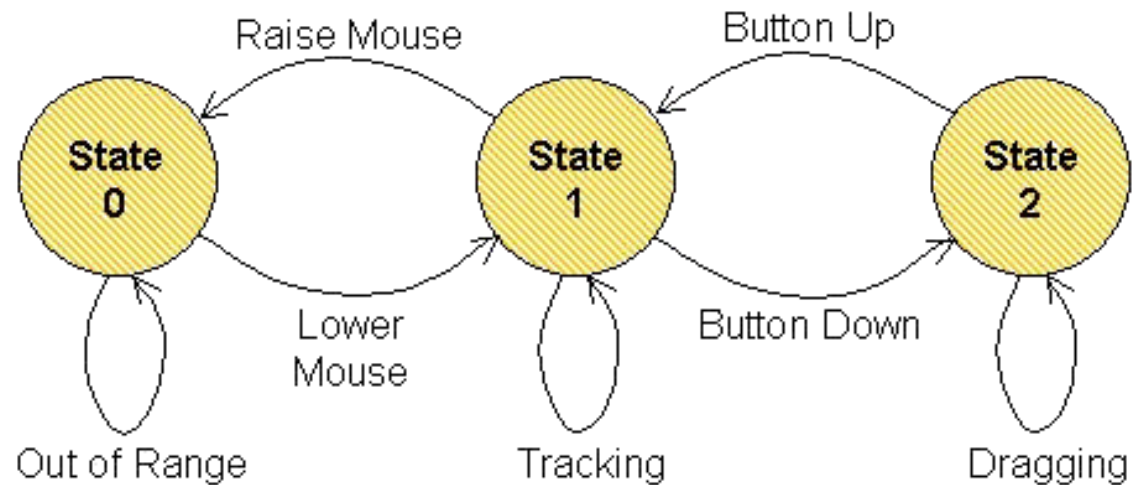
Descriptive Models

- *(The categorisation is not sharp, for more insights, see [MacKenzie 2003])*
- Descriptive models
 - provide a basis for understanding, reflecting, and reasoning about certain facts and interactions
 - provide a conceptual framework that simplifies a, potentially real, system
 - are used to inspect an idea or a system and make statements about their probable characteristics
 - used to reflect on a certain subject
 - can reveal flaws in the design and style of interaction
- Examples:
 - Descriptions, statistics, performance measurements
 - Taxonomies, user categories, interaction categories

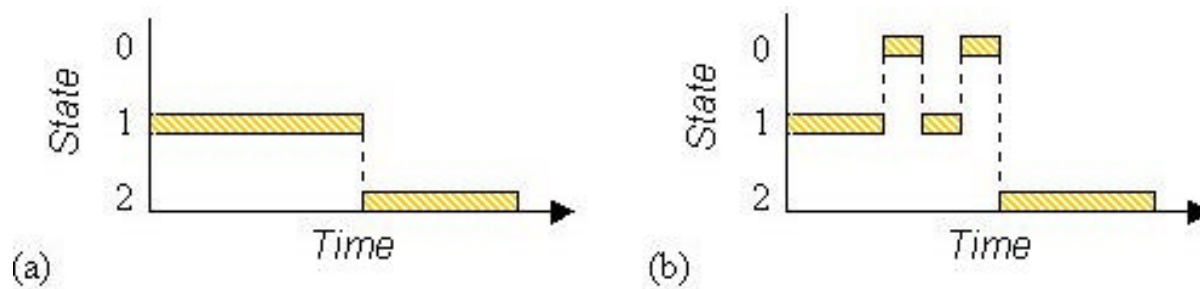
MacKenzie, I. S., 2003, Motor Behaviour Models for Human-computer Interaction
In *HCI Models, Theories, and Frameworks: Toward a Multidisciplinary Science (Book)*, 27-54

Example: Three-State Model (W. Buxton)

- Describes graphical input
- Simple, quick, expressive
- Possible extensions:
 - multi-button interaction
 - stylus input
 - direct vs. indirect input



Buxton, W, 1990, A Three-State Model of Graphical Input
In INTERACT'90, 449-456



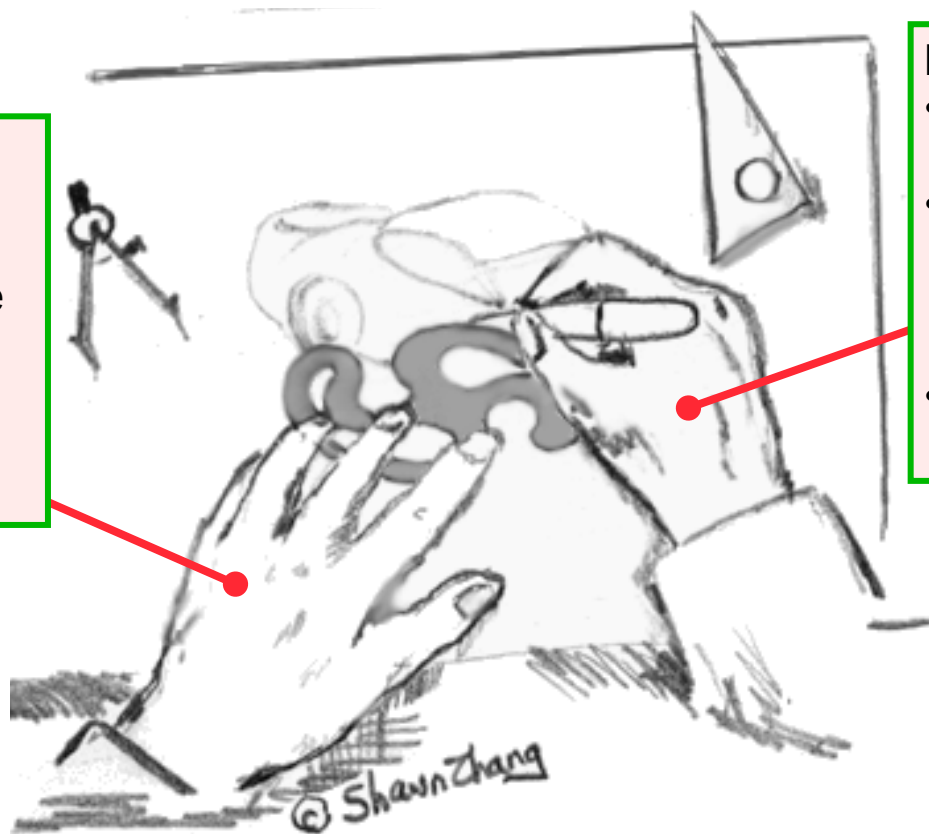
Dragging tasks: (a) mouse (b) lift-and-tap touchpad. [MacKenzie 2003]

Example: Guiard's Model of Bimanual Skill (1 / 2)

- Many tasks are asymmetric with regard to left / right hand
- Guiard's model identifies the roles and actions of the non-preferred and preferred hands

Non-preferred hand

- leads the preferred hand
- sets the spatial frame of reference for the preferred hand
- performs coarse movements

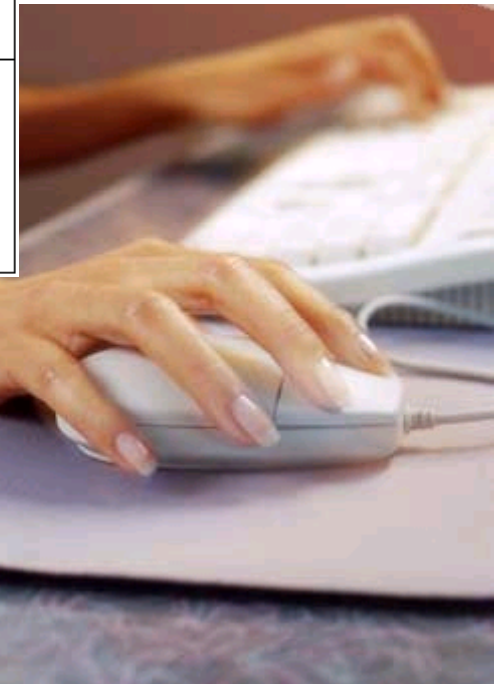


Preferred hand

- follows the non-preferred hand
- works within established frame of reference set by the non-preferred hand
- performs fine movements

Example: Guiard's Model of Bimanual Skill (2 / 2)

Task	Characteristics
Scrolling	• precedes/overlaps other tasks • sets the frame of reference • minimal precision needed (coarse)
Selecting, editing, reading, drawing, etc.	• follows/overlaps scrolling • works within frame of reference set by scrolling • demands precision (fine)



^a Microsoft Office Keyboard

The GOMS Model

- **G:** goals
 - (Verbal) description of what a user wants to accomplish
 - Various levels of complexity possible
- **O:** operators
 - Possible actions in the system
 - Various levels of abstraction possible (sub-goals / ... / keystrokes)
- **M:** methods
 - Sequences of operators that achieve a goal
- **S:** selection rules
 - Rules that define when a user employs which method
- User tasks are split into goals which are achieved by solving sub-goals in a divide-and-conquer fashion

Card, S. K.; Newell, A.; Moran, T. P., 1983, The Psychology of Human-Computer Interaction (Book)

GOMS Example: Move Word (1 / 2)

Goal: move the word starting at the cursor position to the end of the text

[select **use-keyboard**
 delete-and-write
 use-mouse]

verify move

Main goal
with
methods

Goal: **use-keyboard**

Goal: select word

[select use <shift> and n *<cursor right>
 use <shift> and <ctrl> and <cursor right>]
verify selection

Sub-
goal

Method 1

...

Goal: **delete-and-write**

...

Method 2

Goal: **use-mouse**

Goal: select word

[select click at beginning and drag till the end of the word
 double-click on the word]

verify selection

Goal: move word

[select click on word and drag till end of text
 Goal: **copy-paste-with-mouse**
 ...]

Method 3

GOMS Example: Move Word (2 / 2)

- Selection rules:
 - Rule 1: use method **use-keyboard** if no mouse attached
 - Rule 2: use method **delete-and-write** if length of word < 4
 - Rule 3: use method **use-mouse** if hand at mouse before action
 - ...
- Selection rules depend on the user (→ remember user diversity?)
- GOMS models can be derived in various levels of abstraction
 - e.g. goal: write a paper about X
 - e.g. goal: open the print dialog

GOMS Example: Closing a Window

GOAL: CLOSE-WINDOW

```
[select GOAL: USE-MENU-METHOD
      MOVE-MOUSE-TO-FILE-MENU
      PULL-DOWN-FILE-MENU
      CLICK-OVER-CLOSE-OPTION
      GOAL: USE-CTRL-F4-METHOD
      PRESS-CONTROL-F4-KEYS]
```

For a particular user:

Rule 1: Select USE-MENU-METHOD unless another rule applies

Rule 2: If the application is GAME,
select CTRL-F4-METHOD

GOMS Example: ATM Machine

GOAL: GET-MONEY

- . GOAL: USE-CASH-MACHINE
 - . INSERT-CARD
 - . ENTER-PIN
 - . SELECT-GET-CASH
 - . ENTER-AMOUNT
 - . COLLECT-MONEY (outer goal satisfied!)
 - . COLLECT-CARD

GOAL: GET-MONEY

- . GOAL: USE-CASH-MACHINE
 - . INSERT-CARD
 - . ENTER-PIN
 - . SELECT-GET-CASH
 - . ENTER-AMOUNT
 - . COLLECT-CARD
 - . COLLECT-MONEY
(outer goal satisfied!)

GOMS Example: ATM Machine

- GOMS gives an early understanding of interactions
- “How to *not* loose you card”

GOAL: GET-MONEY

. GOAL: USE-CASH-MACHINE

. INSERT-CARD

. ENTER-PIN

. SELECT-GET-CASH

. ENTER-AMOUNT

. COLLECT-MONEY

(outer goal satisfied!)

. COLLECT-CARD

GOAL: GET-MONEY

. GOAL: USE-CASH-MACHINE

. INSERT-CARD

. ENTER-PIN

. SELECT-GET-CASH

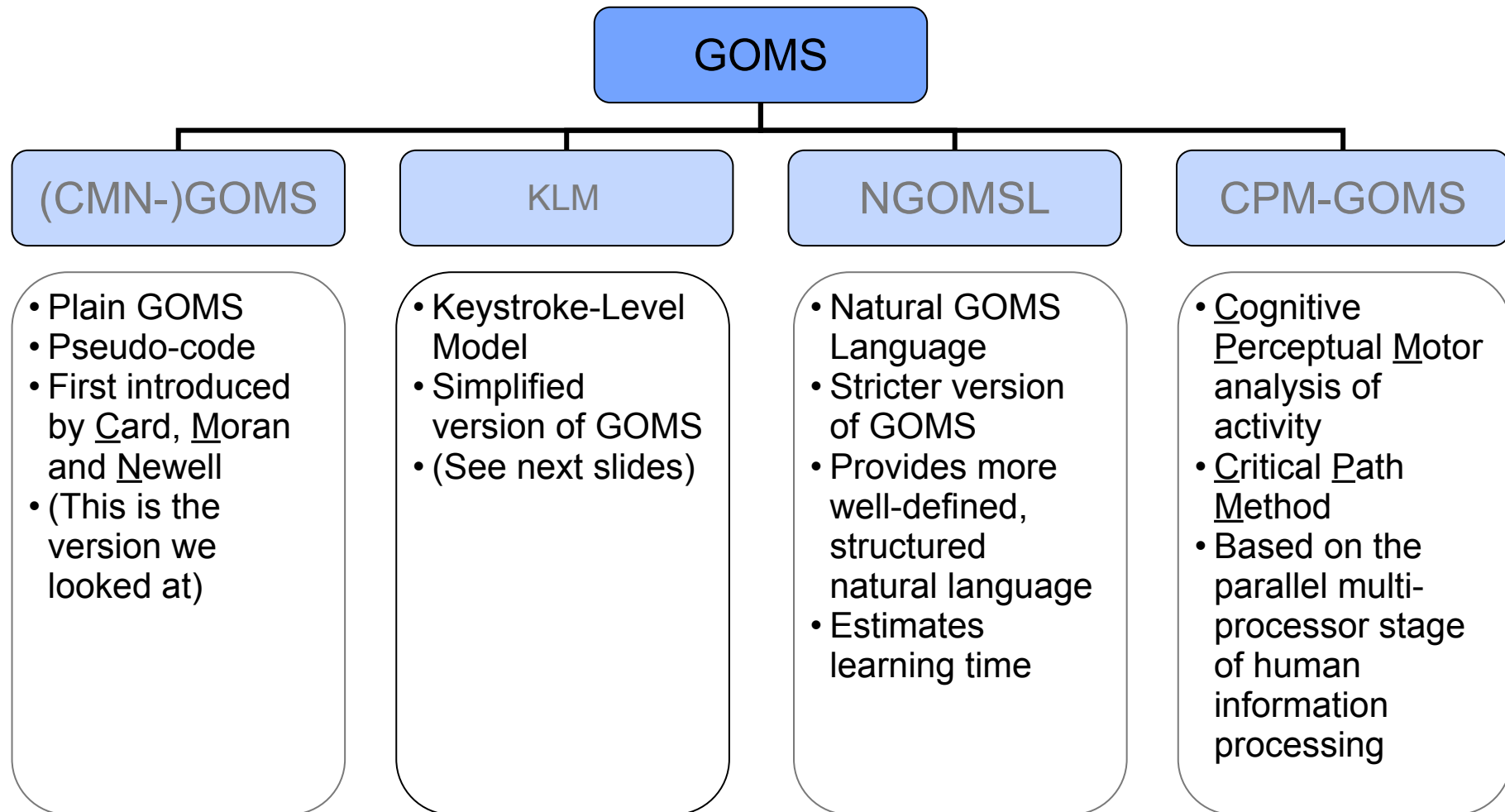
. ENTER-AMOUNT

. COLLECT-CARD

. COLLECT-MONEY

(outer goal satisfied!)

Some GOMS Variations



John, B., Kieras, D., 1996, Using GOMS for user interface design and evaluation: which technique?
ACM Transactions on Computer-Human Interaction, 3, 287-319.

GOMS – Characteristics

- Usually one high-level goal
- Measurement of performance: high depth of goal structure
→ high short term-memory requirements
- Predict task completion time (see KLM in the following)
→ compare different design alternatives

Keystroke-Level Model

- Simplified version of GOMS
 - only operators on keystroke-level
 - no sub-goals
 - no methods
 - no selection rules
- KLM predicts how much time it takes to execute a task
- Execution of a task is decomposed into primitive operators
 - Physical motor operators
 - » pressing a button, pointing, drawing a line, ...
 - Mental operator
 - » preparing for a physical action
 - System response operator
 - » user waits for the system to do something

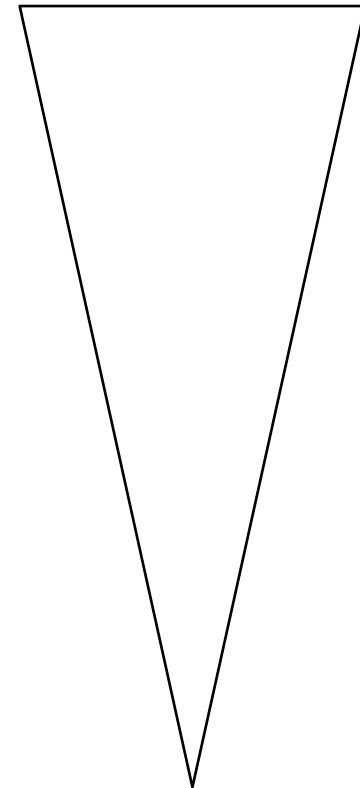
Models: Levels of Detail

- Different levels of detail for the steps of a task performed by a user

- **Abstract:** correct wrong spelling

- **Concrete:** mark-word
delete-word
type-word

- **Keystroke-Level:** hold-shift
n·cursor-right
recall-word
del-key
n·letter-key



KLM Operators

- Each operator is assigned a duration (amount of time a user would take to perform it):

Operator	Description	Associated Time
<i>K</i>	Keystroke, typing one letter, number, etc. or function key like 'CTRL', 'SHIFT'	Expert typist (90 wpm): 0.12 sec Average skilled typist (55 wpm): 0.20 sec Average non-secretarial typist (40 wpm): 0.28 sec Worst typist (unfamiliar with keyboard): 1.2 sec
<i>H</i>	'Homing', moving the hand between mouse and keyboard	0.4 sec
<i>B / BB</i>	Pressing / clicking a mouse button	0.1 sec / 2*0.1 sec
<i>P</i>	Pointing with the mouse to a target	0.8 to 1.5 sec with an average of 1.1 sec Can also use Fitts' Law
<i>D(n_D, l_D)</i>	Drawing n_D straight line segments of length l_D	$0.9 * n_D + 0.16 * l_D$
<i>M</i>	Subsumed time for mental acts; sometimes used as 'look-at'	1.35 sec (1.2 sec according to [Olson and Olson 1995])
<i>R(t)</i> or <i>W(t)</i>	System response (or 'work') time, time during which the user cannot act	Dependent on the system, to be determined on a system-by-system basis

Predicting the Task Execution Time

- Execution Time

- OP: set of operators
- n_{op} : number of occurrences of operator op

$$T_{execute} = \sum_{op \in OP} n_{op} \times op$$

- Example task on Keystroke-Level:

1. hold-shift
2. $n \cdot$ cursor-right
3. recall-word
4. del-key
5. $n \cdot$ letter-key

Sequence:

K (Key)

$n \cdot$ K

M (Mental Thinking)

K

$n \cdot$ K

- Operator Time Values: K = 0.28 sec. and M = 1.35 sec

$$2n \cdot K + 2 \cdot K + M = 2n \cdot 0.28 + 1.91 \text{ sec}$$

- → time it takes to replace a $n=7$ letter word: T = 5.83 sec

Keystroke-Level Model – Example Task

Task: in MS Word, add a 6pt space after the current paragraph

→ Word 2003:

Actions	Operator (keyboard)	Time allocated	Operator (mouse)	Time allocated
Locate menu 'Format'	<i>M</i>	1.35	<i>M</i>	1.35
Press ALT-o or mouse click	<i>K,K</i>	2*0.28	<i>P,B</i>	1.10+0.10
Locate entry 'Paragraph'	<i>M</i>	1.35	<i>M</i>	1.35
Press 'p' or mouse click	<i>K</i>	0.28	<i>P,B</i>	1.10+0.10
Locate item in dialogue	<i>M</i>	1.35	<i>M</i>	1.35
Point to item	<i>K,K</i>	0.28	<i>P,B</i>	1.10+0.10
Enter a 6 for a 6pt space	<i>K</i>	0.28	<i>K</i>	0.28
Close the dialogue (ENTER)	<i>K</i>	0.28	<i>K</i>	0.28
		Sum (keyboard): 5.73 sec.		
			Sum (mouse): 8.21 sec.	

→ Word 2007:

Sum (keyboard): 7.22 sec.

Sum (mouse): 7.65 sec.

GOMS vs. KLM

(CMN-)GOMS

- Pseudo-code (no formal syntax)
- Very flexible
- Goals and subgoals
- Methods are informal programs
- Selection rules
 - ⇒ tree structure: use different branches for different scenarios
- Time consuming to create

KLM

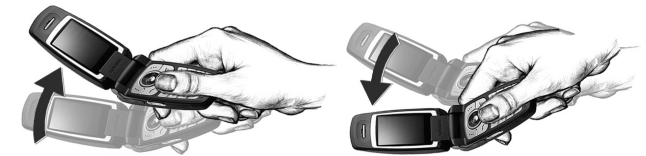
- Simplified version of GOMS
- Only operators on keystroke-level
 - ⇒ focus on very low level tasks
- No multiple goals
- No methods
- No selection rules
 - ⇒ strictly sequential
- Quick and easy

Problem with GOMS in general

- Only for well defined routine cognitive tasks
- Assumes statistical experts
- Does not consider slips or errors, fatigue, social surroundings, ...

Extensions for Novel Mobile Interactions

- Current mobile interactions use
 - Keypad, hotkeys
 - Microphone, camera (marker detection)
 - Sensors like accelerometers
 - Tag readers (NFC)
 - Bluetooth
- Method
 - Large set of studies
 - Software on the phone
 - Video frame-by-frame analysis
 - Eye-tracker
 - Total number of actions measured: 2134



KLM – Original and New Operators

- Mental Act, M
 - System Response, R
- ← unchanged

- Keystroke / button press, K
 - Homing, H
 - Pointing, P
- ← adopted

- Micro attentions Shift, S_{Micro}
 - Macro attention shift, S_{Macro}
 - Finger movement F
 - Distraction X
 - Gesture G
 - Initial preparation I
- ← added

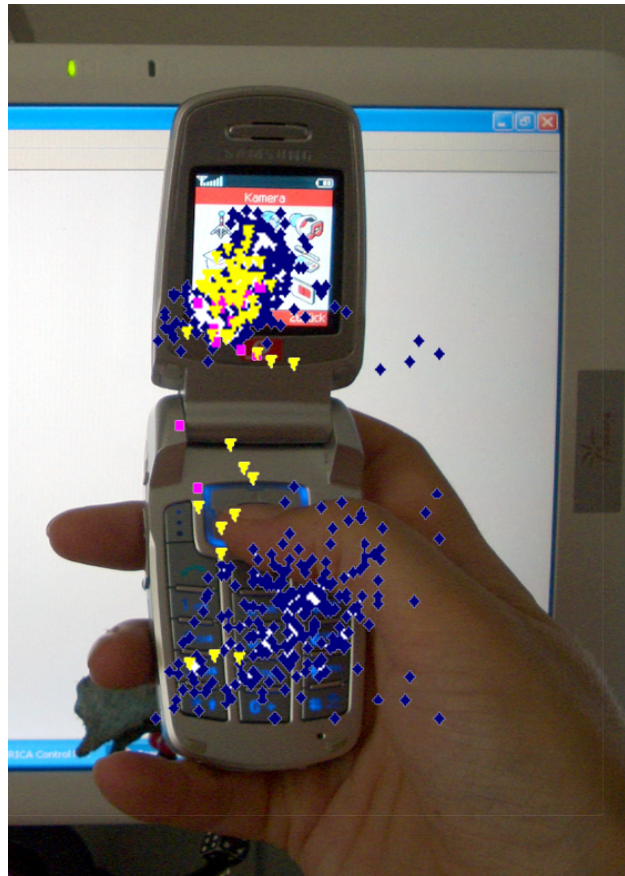
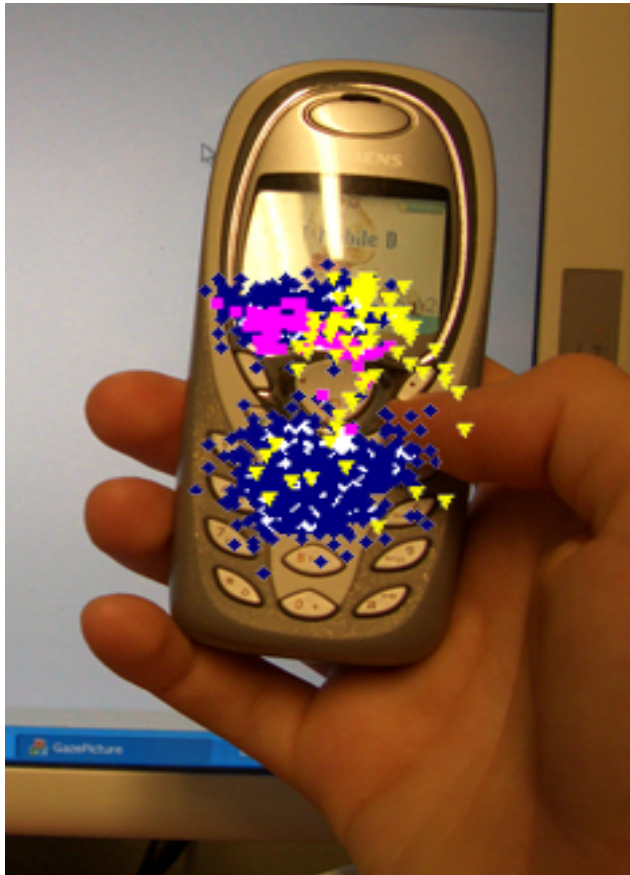
Micro Attention Shift, S_{Micro}

Switch attention between phone parts



S_{Micro} – Operator Time Estimation

- Measured with a standard eye tracker
- Mobile phone in front of the monitor



S_{Micro} – Operator Time Estimation

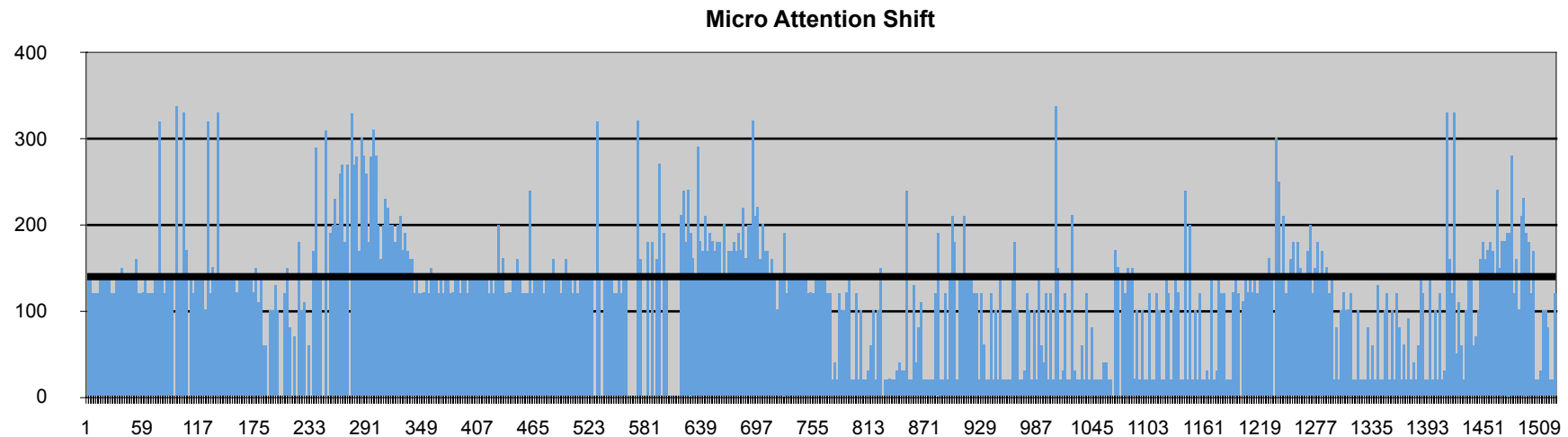
Study

- 10 participants, 24-34 years, 6 female
- 1500 shifts detected
- Using automatic eye-tracking
- 3 pre-set tasks

display ↔

hotkeys: 0.14 sec.

display ↔ keypad: 0.12 sec.



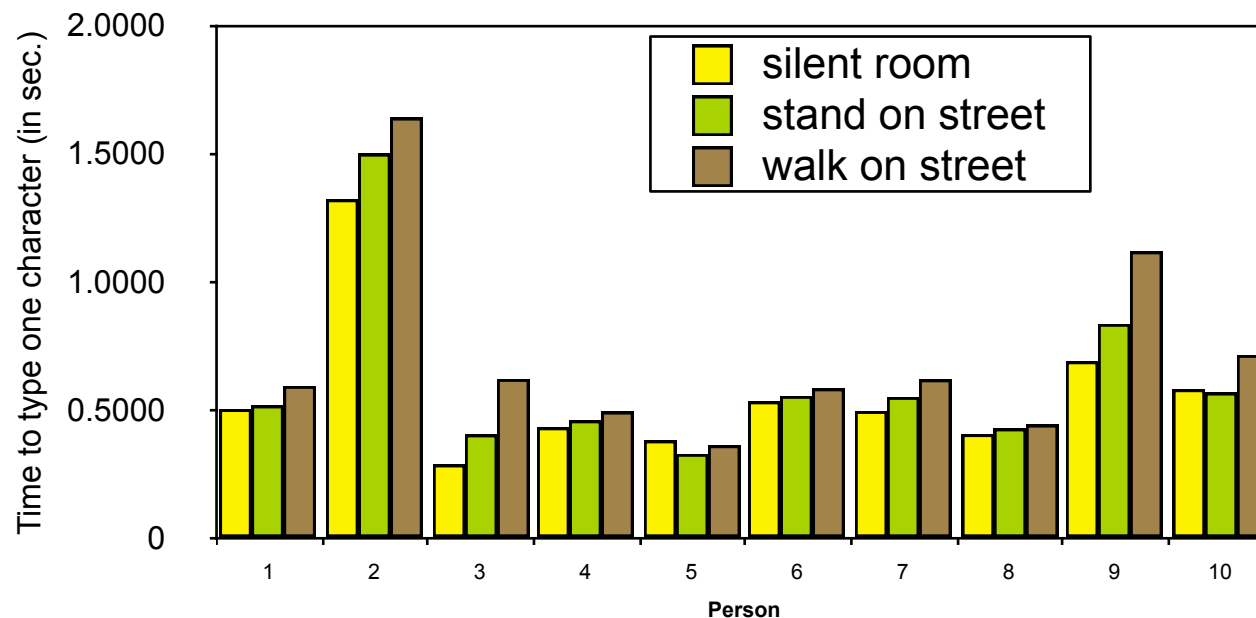
Distraction, X

Study

- 10 participants, 24-33 years, 3 female
- Short message in 3 settings (quiet room, standing outside, walking)
- Relative slow-down (significant: $t=2.23$, $p<0.03$ and $t=3.28$, $p<0.01$)

Distraction: multiplicative

$$X_{\text{slight}} = 6\%, X_{\text{strong}} = 21\%$$



Extended KLM – Time Prediction

Total Execution Time:

$$T_{execute} = \sum_{op \in OP} (n_{op} + d_{op} \times X_{slight} + D_{op} \times X_{strong}) \times op$$

Set of Available Operators:

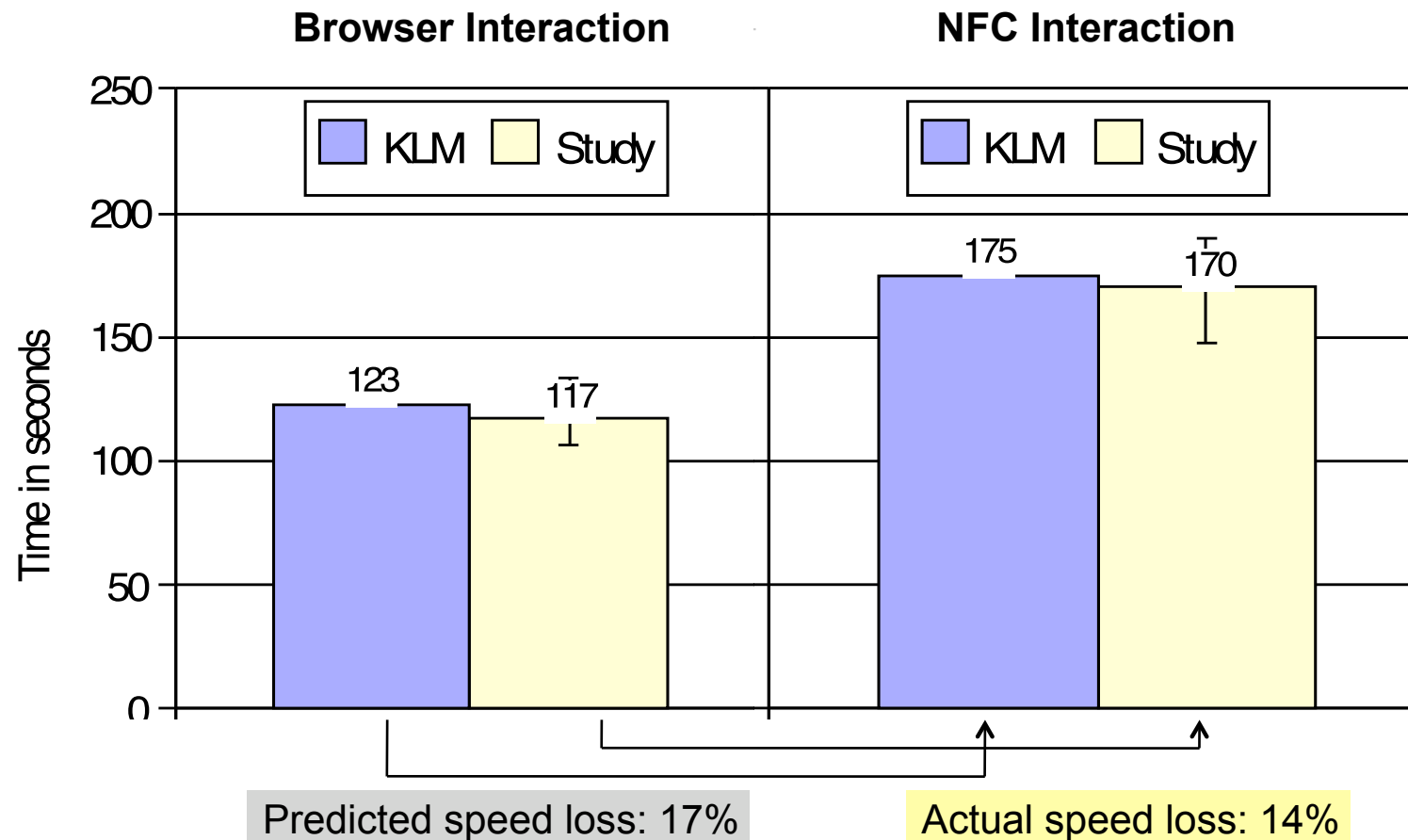
$$OP = \{A, F, G, H, I, K, M, P, R, S_{Micro}, S_{Macro}\}$$

Extended KLM – Empirical Validation

- Task: buy a public transportation ticket from A to B
- Implemented 2 ways of performing the task
 - Access through mobile web browser
 - Direct interaction with NFC tags
- Created the two Keystroke-Level Models
- Study: 9 people, 23-34 years, 3 female



Extended KLM – Empirical Validation



Advanced Mobile Phone KLM – Values

Operator		Time	Qu. 1	Qu. 3
A, Action	picture / marker	1.23	0.61	1.44
	NFC	0.00	-	-
	in general	<i>variable, input to model</i>		
B, Mouse Button Press		<i>not applicable</i>		
D, Mouse Drawing		<i>not applicable</i>		
F, Finger Movement		0.23	0.20	0.29
G, Gestures		0.80	0.73	0.87
H, Homing		0.95	0.81	1.00
I, Initial Act	external trigger	5.32	3.98	7.51
	self triggered	3.89	2.23	4.89
	optimal setting	1.18	1.10	1.26
	no assumptions	4.61	-	-
K, Keystroke	keypad average	0.39	0.37	0.48
	keypad quick	0.33	0.32	0.37
	hotkey	0.16	0.15	0.20

Operator		Time	Qu. 1	Qu. 3
M, Mental Act		1.35	-	-
P, Pointing		1.00	0.84	1.20
R, System Response Time	NFC	2.58	2.46	2.80
	visual marker	2.22	2.09	2.82
	in general	<i>variable, input to model</i>		
S_{Macro}, Macro Attention Shift		0.36	0.28	0.44
S_{Micro}, Micro Attention Shift	keypad ↔ display	0.14	0.14	0.19
	hotkey ↔ display	0.12	0.02	0.14
	keypad ↔ hotkey	0.04	0.02	0.12
	in general	0.14	0.10	0.16
X, Distraction	slight	6 %	3 %	13 %
	strong	21 %	11 %	25 %

Using KLM

- KLM can help evaluate UI designs, interaction methods and trade-offs
- If common tasks take too long or consist of too many statements, shortcuts can be provided
- Predictions are mostly remarkable accurate: +/- 20%

Weaknesses of GOMS et al.

- Just spending time is not modelled
- Difficult to target specific users
- No real users
- Difficult to model novel interactions
- Various variable parameters
- Users like to have impact

Strengths of GOMS et al.

- Good treatment of learning effects
 - Measurement of learnability
 - Independence of sequences
 - Measurement of knowledge requirements
- Good results
 - Gives reasons
 - Helps in decision making
 - Identifies bottlenecks
 - Provides illustrative figures
 - Combines various views
 - Treats feasibility and cognitive load
- Less cost in money and time
 - Quick to apply
 - Quick to prepare
 - Helpful to design
 - Cheap to apply
 - Easy to repeat
 - Quick to analyse
 - Precise to interpret
 - Easy to convey

GOMS / KLM Summary Example

- Example prototype: the Combimouse
- Ergonomic models followed
- Follows Guiard's model of bimanual control
(for right handed people scrolling with the non-preferred hand)
- Removes KLM's Homing operator ($H \sim 1 \text{ sec.}$)



<http://www.combimouse.com>

References

GOMS

- Card S. K., Newell A., Moran T. P. (1983). The Psychology of Human-Computer Interaction. *Lawrence Erlbaum Associates Inc.*
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KLM

- Kieras, D. (1993, 2001). Using the Keystroke-Level Model to Estimate Execution Times. *University of Michigan. Manuscript.*

Mobile Phone KLM

- Holleis, P., Otto, F., Hussmann, H., Schmidt, A. (2007). Keystroke-Level Model for Advanced Mobile Phone Interaction, *CHI '07*