MLMI10
Designing Intelligent Interactive Systems

Lecture 1

Per Ola Kristensson

Lent 2022

MLMI10 Designing Intelligent Interactive Systems

- **Course Coordinator and Lecturer**
  - Professor Per Ola Kristensson

- 100% Coursework
- Module information available on Moodle
- All information will be made available on Moodle

Overview

- This module aims to teach you theories and methods that allow you to design AI-infused user interface systems
- There is no *textbook* or *school of thought* that can assure you on your steps towards a designer within this specialism
- Rather, this is a cross-disciplinary endeavor that is still actively researched spanning several fields:
  - Human-computer interaction
  - Design
  - Engineering Design
  - Human factors and ergonomics

Coursework

- The best way to learn design is to *design*
- Hence this module will be examined by 100% coursework
- You will all be asked to propose an intelligent interactive system (more on this later)
- During this module you will gradually create a 10-page double column design document
- The lecture content will be a mix of design engineering and material specific to intelligent interactive systems

Rules and advice

- Attendance is **mandatory**
- Some lectures requires a 1-minute presentation; with feedback
- Assessed as 100% course work
  - This will be a **single** final report in double-column format, maximum 10 pages
- Material and course information is provided on Moodle
- Since your coursework task is open-ended, a vast amount of material will be provided; not all this material might be useful for an individual piece of coursework—learn to filter and quickly find relevant material (a transferrable skill!)

Design

Design concerns

- Aesthetics
- Ease of use
- Cost
- Business cases
- Safety
- Effectiveness
- Efficiency
- Low risk operation

…

- Exciting
- Engaging
- Amplifying life

Design is a set of decisions

- Assume a multidimensional design space capturing all relevant concerns
- An **artefact** is a design instantiation in this space
- It is in fact an **operating point** in this multidimensional design space
- A design is rarely (if ever) **optimal** (why?)
- Setting the operating point necessitates making informed trade-off decisions
  - **Explicit trade-off decisions:** the designer understood the critical design dimensions and made **informed** decisions
  - **Implicit trade-off decisions:** the designer failed to understand and/or capture all critical design dimensions and one or several **uninformed** decisions resulted in an arbitrary design

Why do we have to design?

- **It is humane**
- **Computers are hard**
  - Landauer, T. 1994. *The Trouble with Computers: Usefulness, Usability, and Productivity*. MIT Press. Classic research monograph on the fallacy of naïve computerization of business processes.
  - Core argument: It is insufficient to introduce computers to increase productivity unless such introductions are user-centred and provide individuals with sufficient utility and usability
- **Dignity**
  - Inclusive and considerate design that encompasses all users with empathy
- **It is worth it**
  - The cost of poor usability can be very high: Bias, R. and Mayhew, D. 2005. *Cost-Justifying Usability*, 2nd edition. Morgan Kaufmann.
- **Inventing the future**
- **Product life cycles** (more on this in the next slides)

In a nutshell: what is design

- Design is about arriving at an operating point in a high dimensional design space in an **informed** manner
  - Solving the **right** problem
  - Solving the problem **right**
  - Making trade-offs **explicit**
- There is a **myth** design is…
  - …random; unstructured; unpredictable
- In **reality**, design is:
  - systematic, **principled,** underpinned by engineering science
- An engineer is a designer
- Just like a master painter learns by observing paintings, a master design engineer learns by analysing existing designs

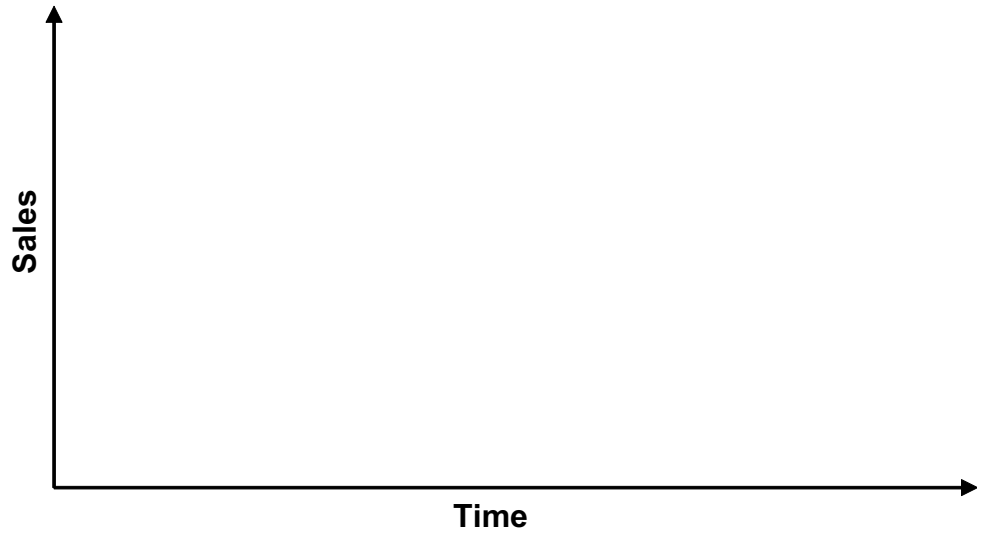
Product Life Cycle

Product Life Cycle (PLC)

- Why research, develop and introduce new products to the market?
  - **Existing products become obsolete**
- Why?
  - **Customer demands**
  - **Competitor products**
  - **Technological advances**
  - **New ideas**
  - **Increasing regulation**
  - **Economic climate**

Product lifecycle

A *typical* product life cycle is shown below. There are also several other well-known forms of product life cycle that may be found in books on marketing.



Source: adapted from 'Marketing Management - Analysis, planning, implementation and control', P Kotler, 6th edition, Prentice Hall (BO251).

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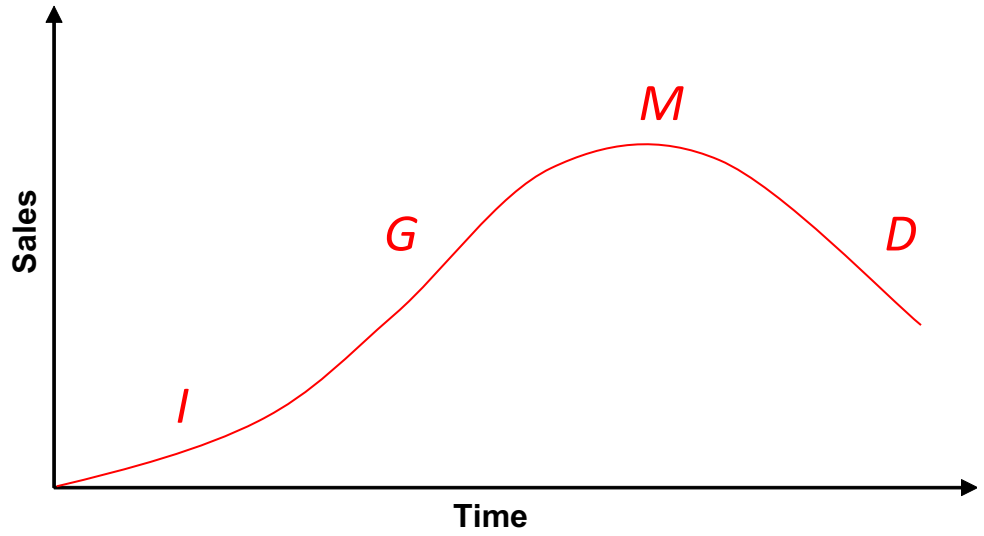

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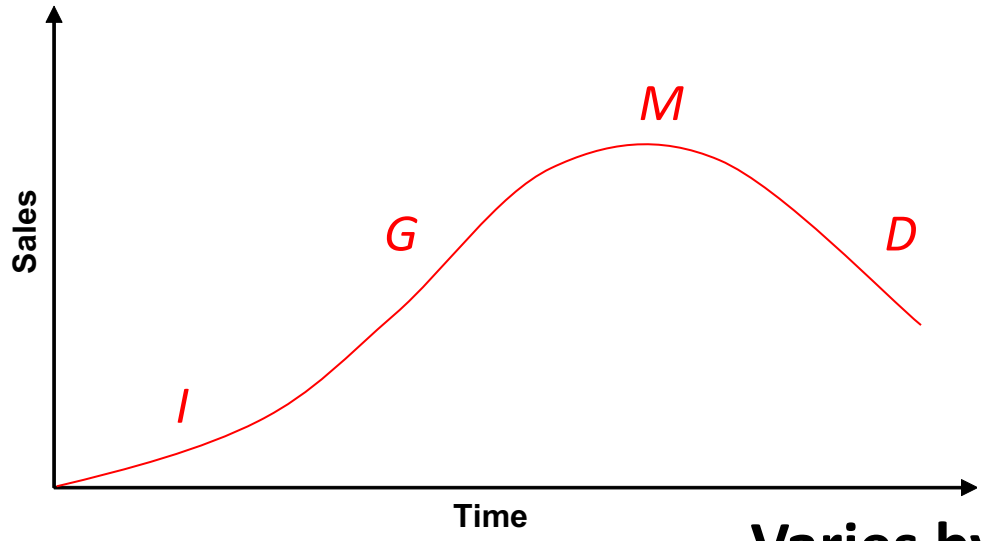


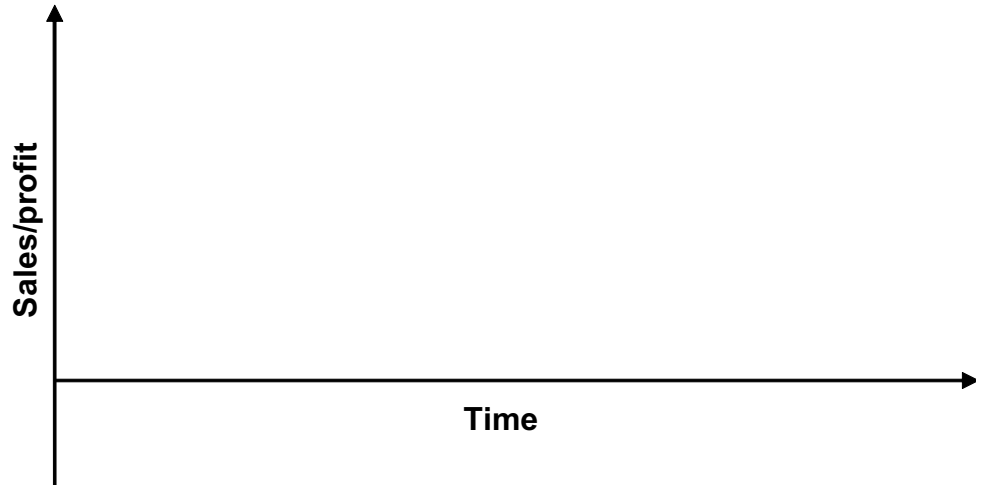
Varies by product

Source: adapted from 'Marketing Management - Analysis, planning, implementation and control', P Kotler, 6th edition, Prentice Hall (BO251).

Product lifecycle

The product life cycle has four key phases:

- Introduction (I):
- Growth (G):
- Maturity (M):
- Decline (D):



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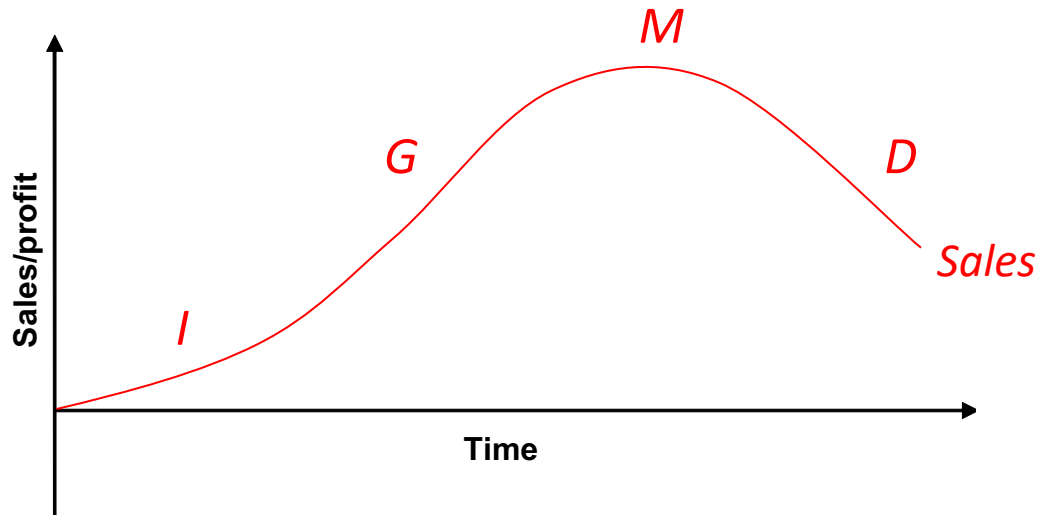

Product lifecycle

The product life cycle has four key phases:

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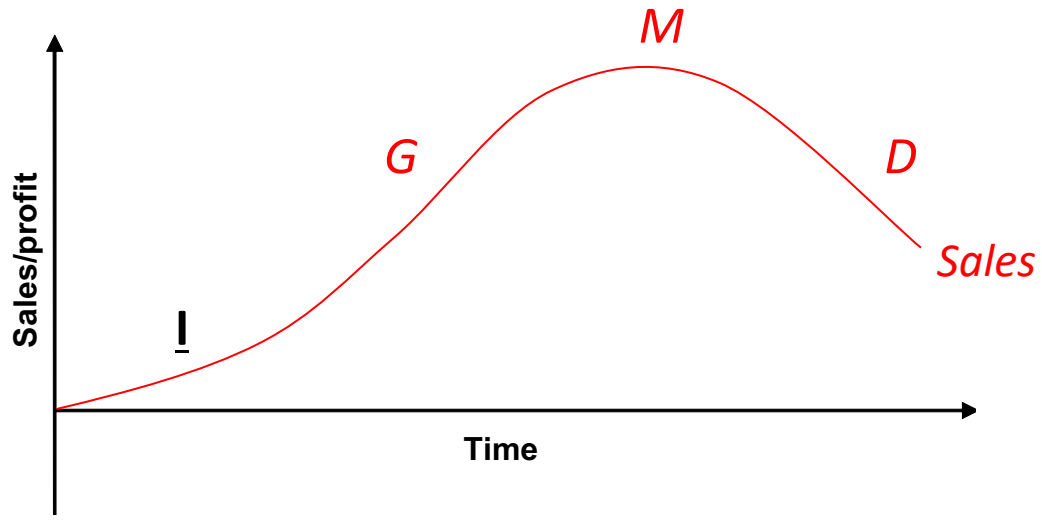

Product lifecycle

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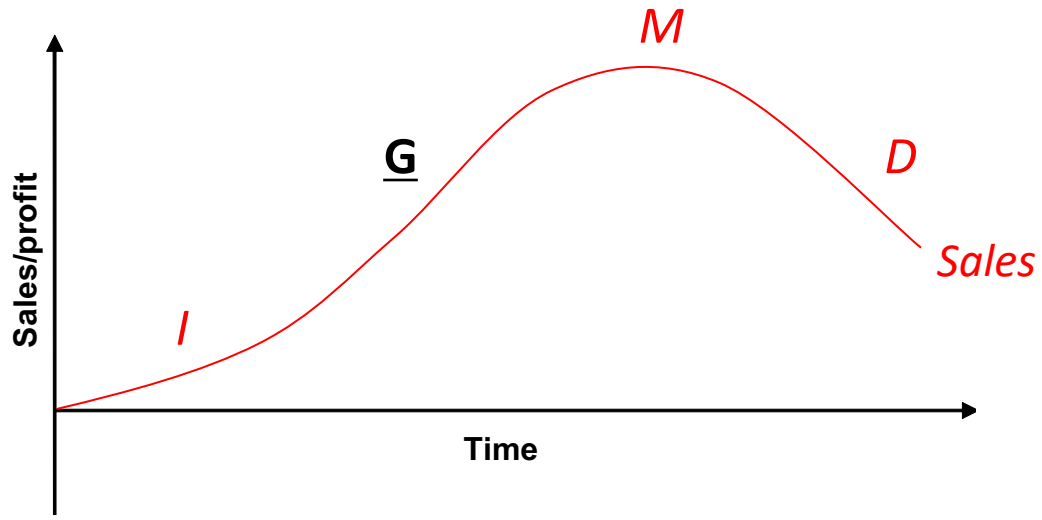

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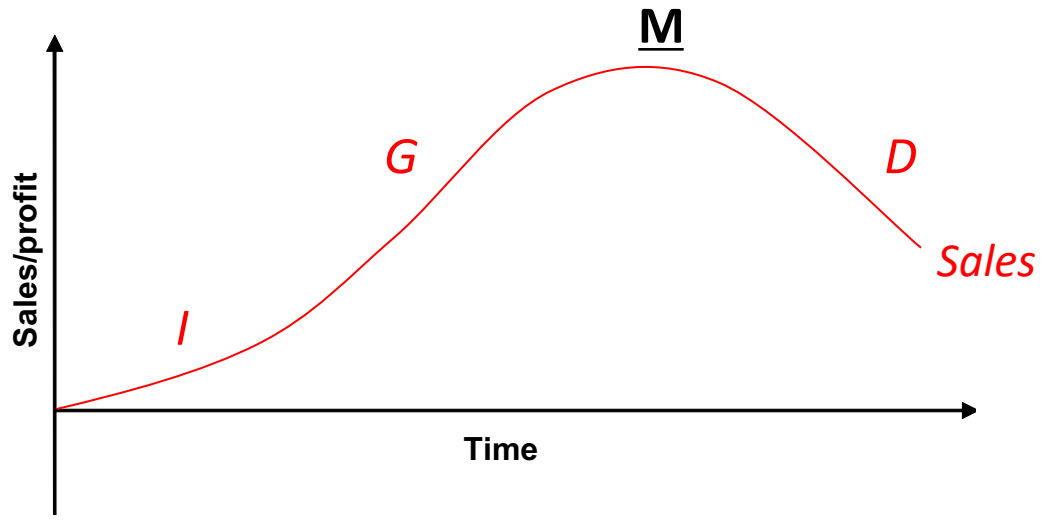

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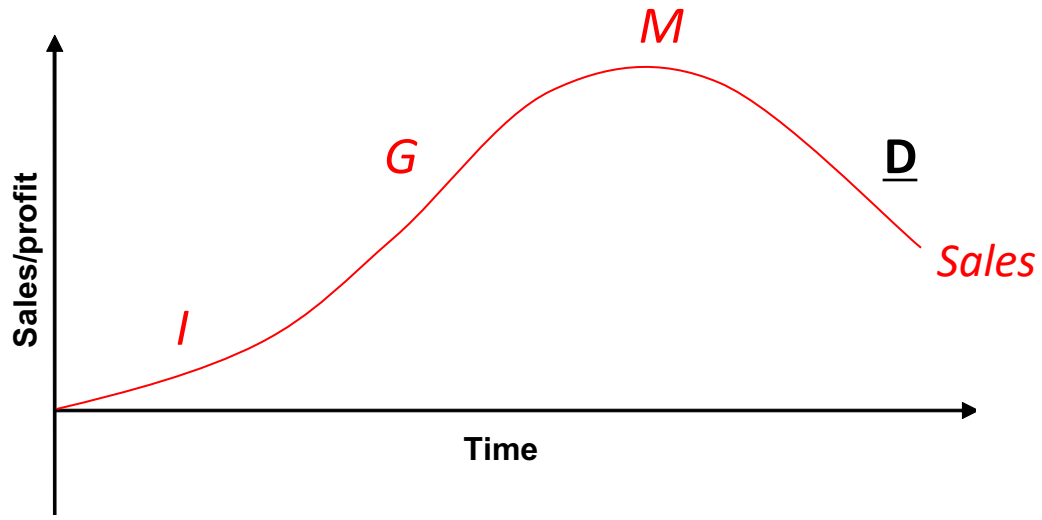

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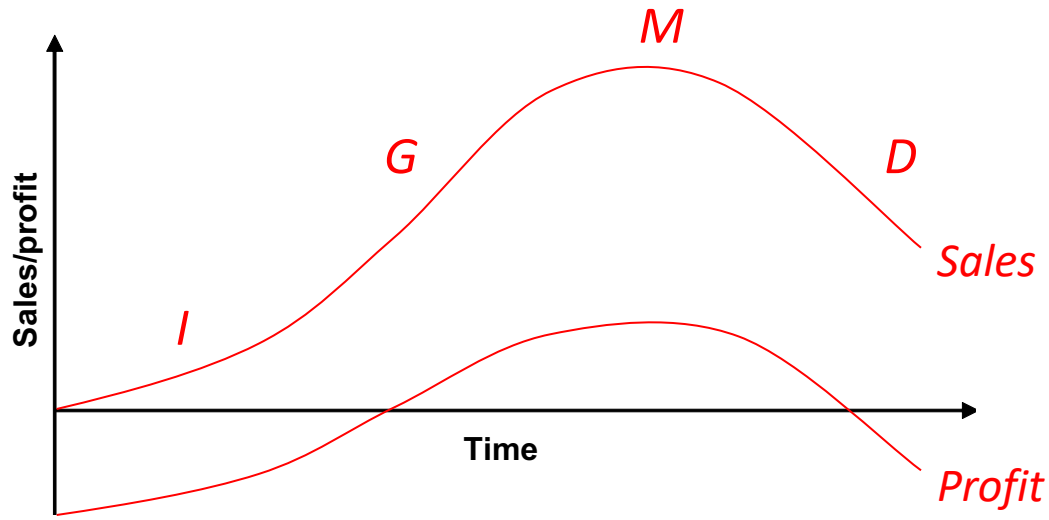

A typical sales/profit life cycle

Product lifecycle

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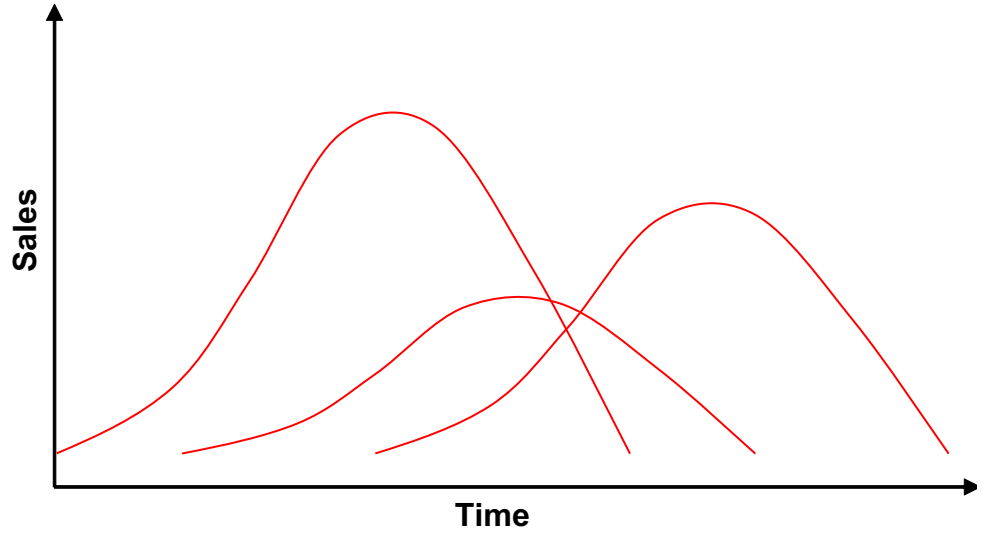
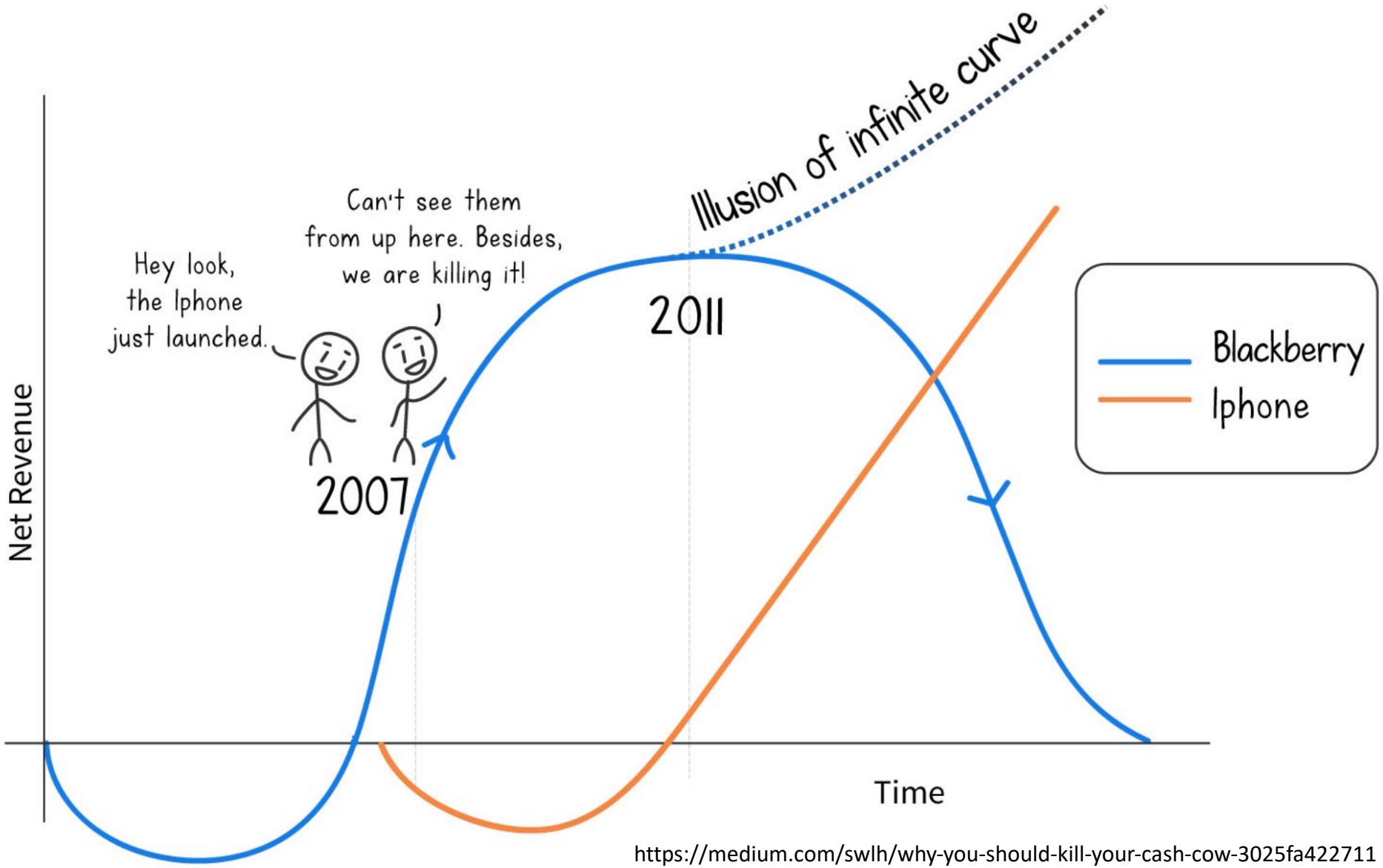
- A successful company is likely to have a product portfolio with products that are mature, growing or declining.



Product lifecycle

- Successful management of product portfolios is **critical** to the success of companies
- Product life cycles show that:
  - Products have a limited life
  - Product sales pass through distinct stages, each posing different challenges to the seller
  - Product profits rise and fall at different stages of the product life cycle
  - Timely launch of the right new product is crucial

Impact

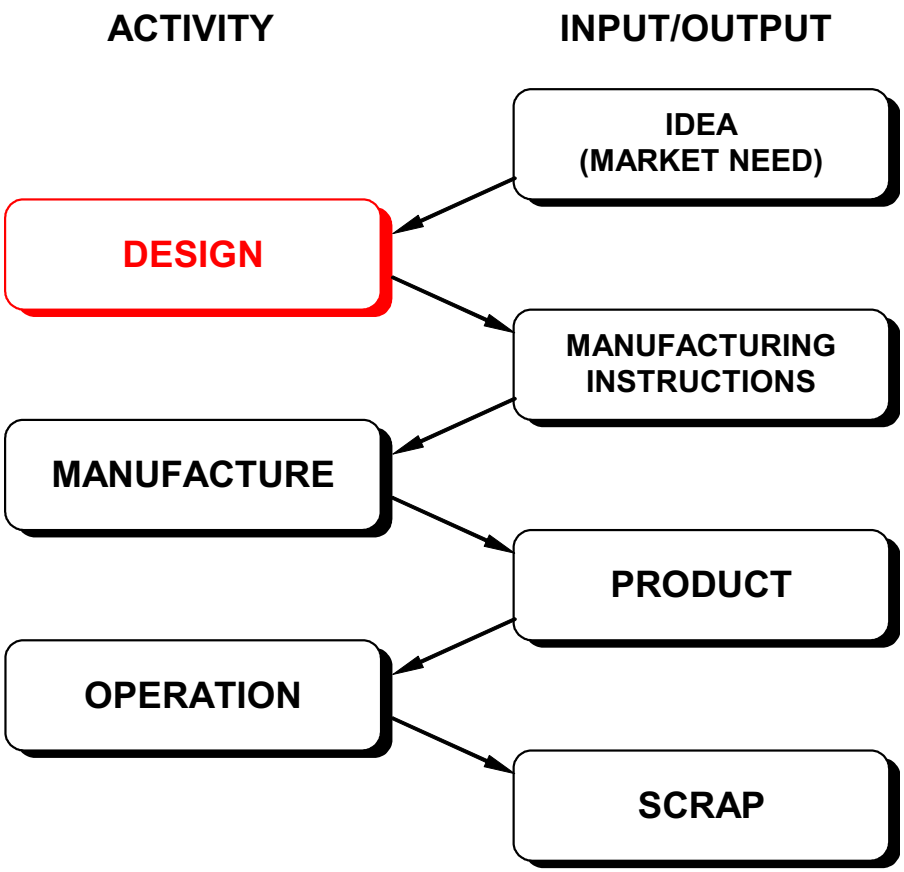


https://medium.com/swlh/why-you-should-kill-your-cash-cow-3025fa422711

Design is a Process

Product Development Cycle (PDC)

A simplified product creation sequence is shown below:



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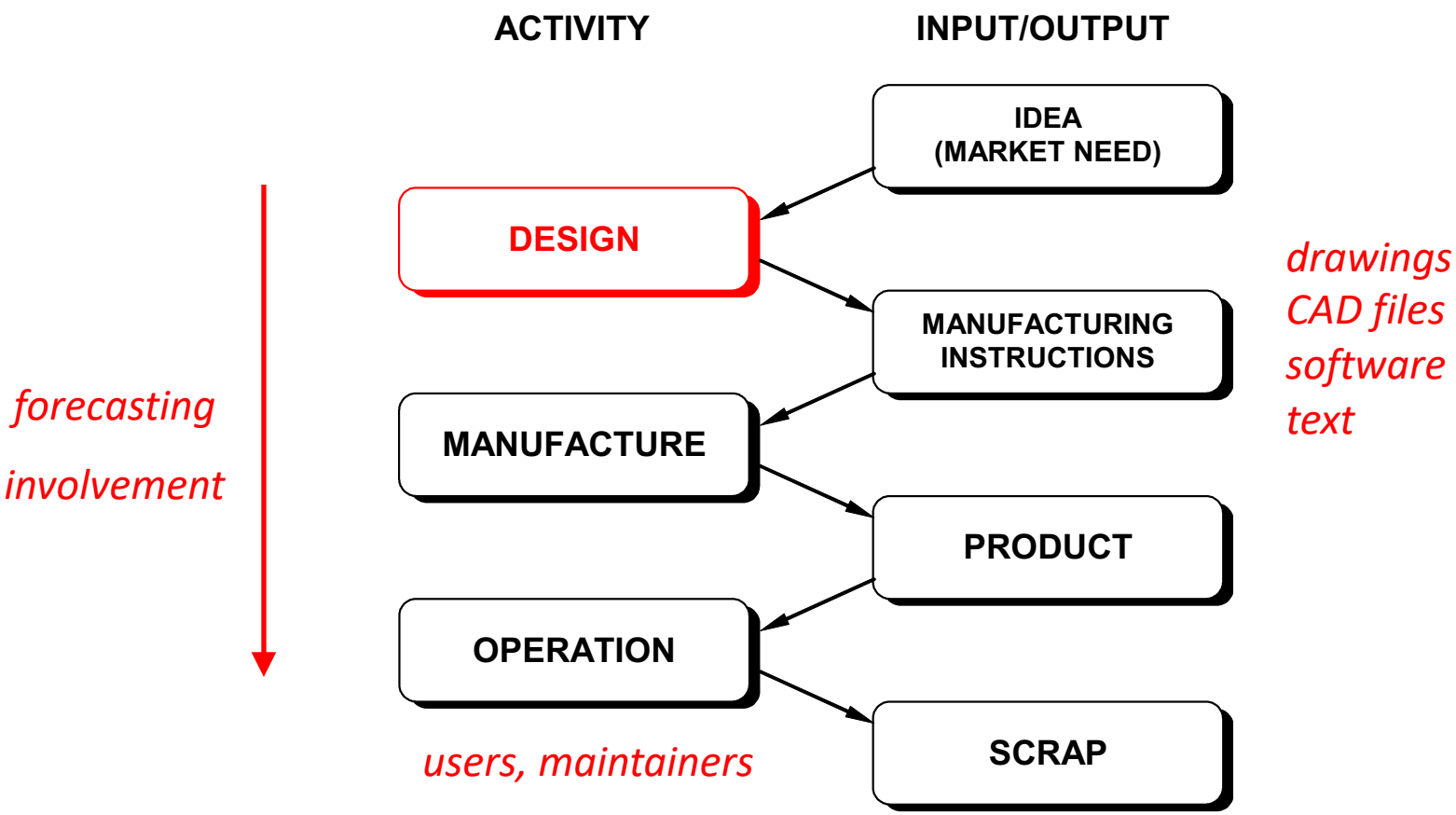


Product development cycle

The key question is: how can we create better products?

not optimal

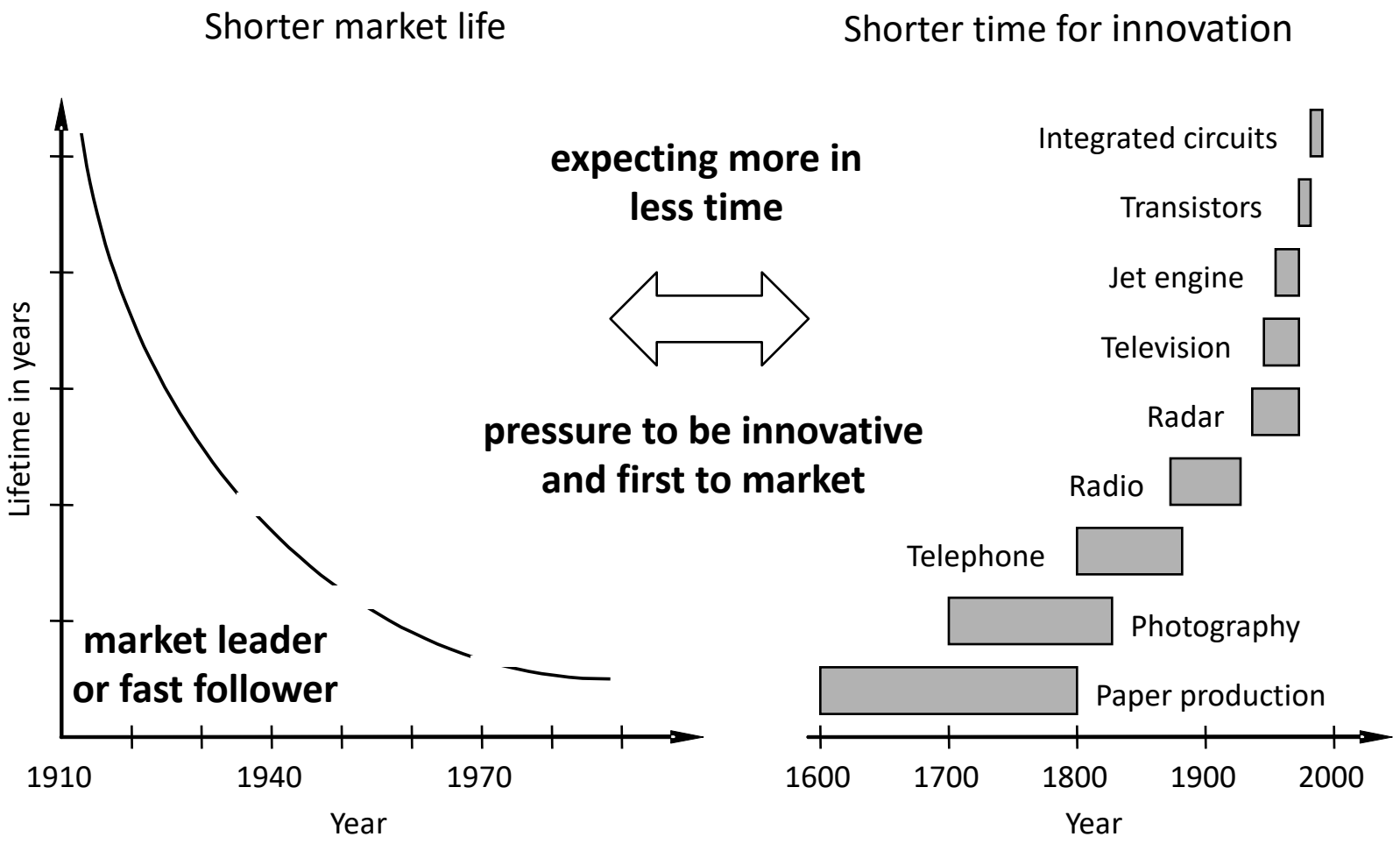
Only 50% of new products succeed.

Successful product development is dependent upon the:

- Product: *complexity*
- Design team: *multi-disciplinary*
- Design process: *intuitive / systematic*
- Design resource: *availability*
- Design context: *viewpoint – components/system/product/service*

Product development cycle

External pressures on product development are ever increasing



General approaches

Design may be intuitive:

- Freedom: **No constraints**
- Creative: **Brainstorming**
- Fun → **Risky**

or systematic: → **Framework** → **Reduces risk**

- Discipline: **Methodical**
- Structured: **Functions**
- Boring → **Fun**

or a balanced mutually supportive **mix** of the two.

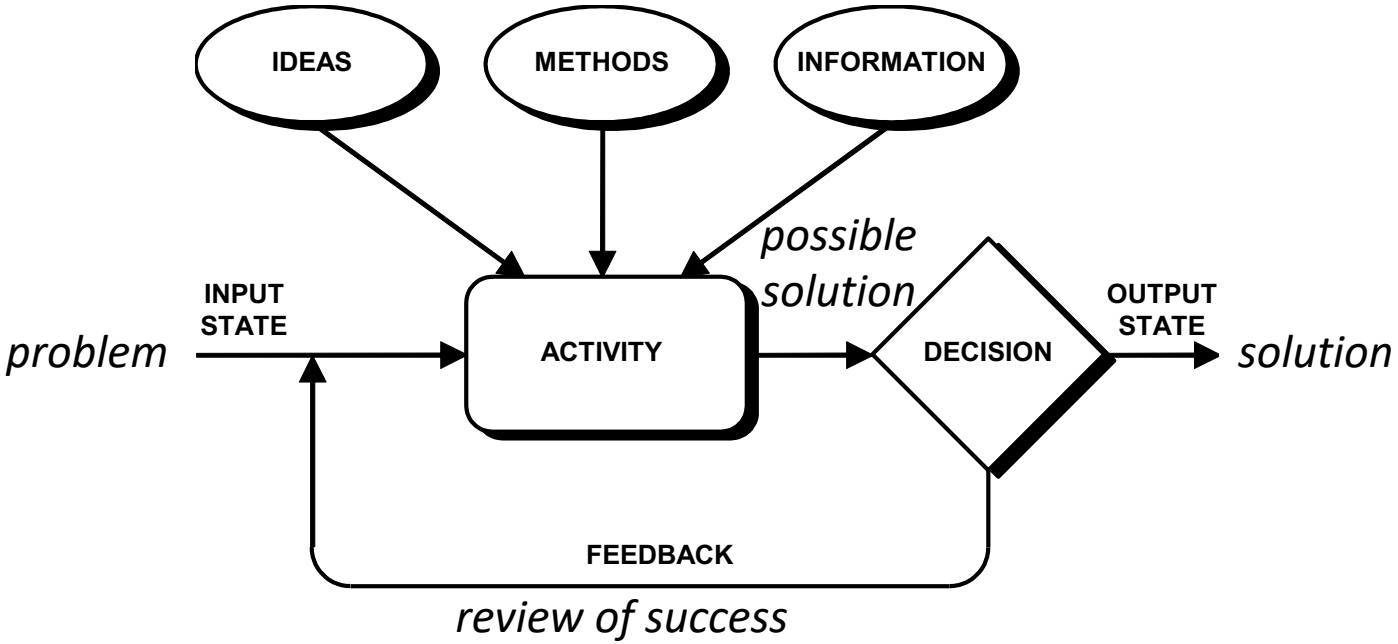
Problem solving

Solving problems involves the following activities:

- Identifying the problem: *defining the problem, establishing the criteria for success*
- Solving the problem: *generating options, evaluating options, selecting the best*
- Implementing the solution: *build it*
- Reviewing the outcome: *building up experience*

Problem solving

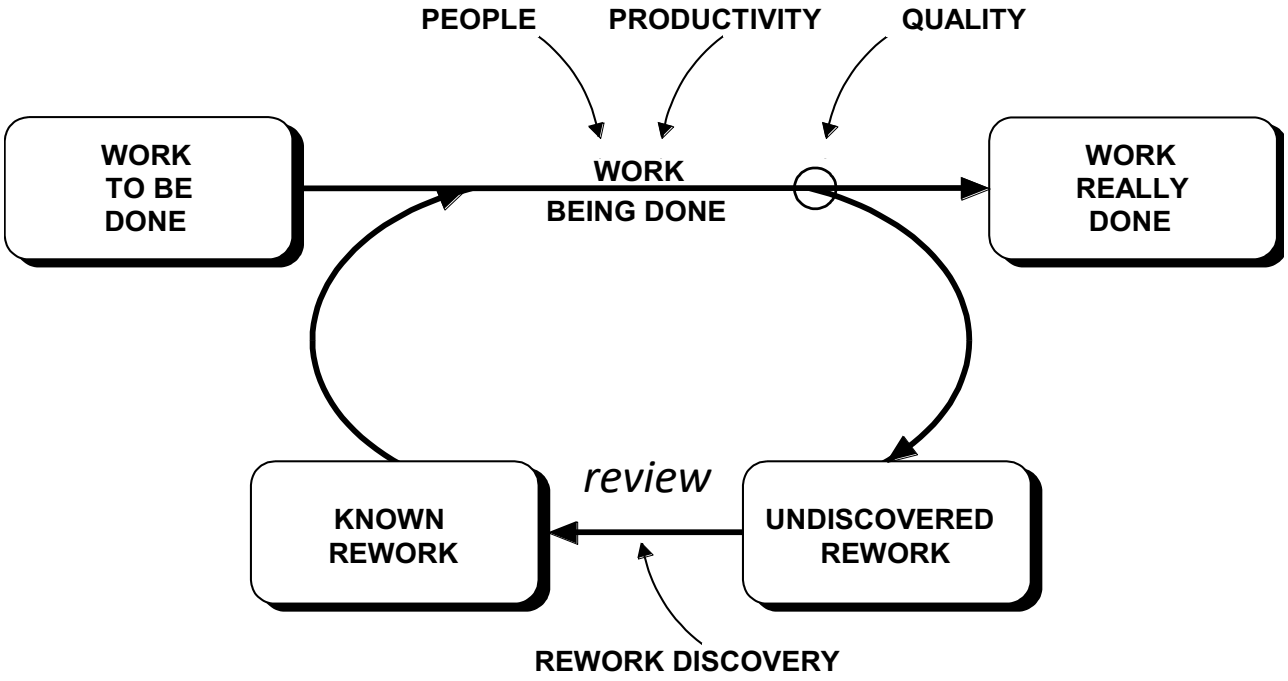
Problem solving can be thought of as a form of elementary information processing



The number of iterations depends upon the quality of ideas, methods, information and the processing activity. Inevitably, more than one iteration is required, which may lead to increased timescales and costs. The decisions and decision criteria are also critical

Problem solving

The effect of design iteration may be explained at the project level by the rework cycle.



Source: 'The Rework Cycle', K G Cooper, Director, Management Simulation Group, March 1993, PA Consulting Group.

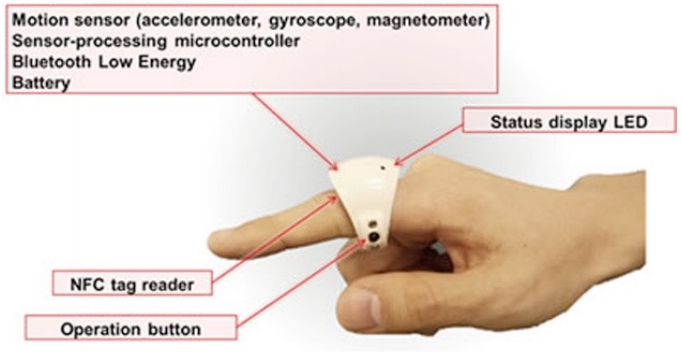
Intelligent Interactive Systems

Intelligent interactive system

- An **interactive system** is a system that requires interaction with a user in order to carry out its overall function
  - Heating control, GUI elements, touchscreen, phone app, web app, lift control panel, etc.
- An **intelligent interactive system** is an interactive system that relies on AI in order to carry out its overall function
  - Recommender system, dialogue system, human-robot interaction, auto-correct keyboard, human-in-the-loop systems, etc.

Intelligent interactive systems are everywhere

http://www.anandtech.com/show/8810/wearables-2014-and-beyond



http://www.engadget.com/2015/01/13/fujitsu-handwriting-ring/

http://www.tomsguide.com/us/google-glass,news-17711.html

http://static0.fitbit.com/simple.b-cssdisabled-png.he2e3da70d98b34b28ddbee568cbd794c.pack?items=%2Fcontent%2Fassets%2Fonezip%2Fimages%2Ffeatures-content%2Fflex%2Fflex_02.png

Application areas

- Basic mobile phone interaction (gesture typing, auto-correct, speech input/output, adaptive user interfaces, context-dependent user interfaces)
- Pervasive health monitoring devices
- Recommender systems
- Optical see-through head-mounted display interaction (typing in thin air, 3D gestural manipulation, adaptive visual saliency of interaction elements)
- Dialogue systems, such as chatbots for customer service
- Human-robot interaction
- Medical devices including (fall-detection devices, radiology, diagnosis support)
- Alternative and augmentative communication devices
- Smart manufacturing environments
- Interactive optimization and decision support

- Any many, many more (search the literature!)

Format

Structure

- Lectures will consist of either:
  - Lectures delivered by me, teaching critical design know-how
  - Individual 1-minute presentations with brief feedback (**not assessed but mandatory and for your benefit**)
- Regardless of lecture format I will give you work to do before next lecture
- **Very important to do the work for each lecture**
- While creativity is important in the real-word, you are primarily assessed based on your ability to apply engineering methods correctly

Assessment: report

- Problem formulation, including necessary background and a solution-neutral problem statement [10%]
- Requirements specification, including information on requirements elicitation using for instance user-centred design research methods, FAST diagrams, and usage of checklists [20%]
- Conceptual design, including at least two concepts and a recommendation of a final design [20%]
- Embodiment design sketch, including reasoning about the product architecture, an indication of which sensors and other components will constitute the design, an estimated bill of materials and a discussion of ergonomic and other issues, where applicable [20%]
- Risk assessment, including a chosen risk assessment procedure and a motivation for why this risk assessment procedure is the most suitable for this particular design [10%]
- Verification and validation, including a description of evaluation strategies and clear arguments explaining why these strategies are cost-effective and efficient [10%]
- Overall clarity, structure, use of introduction/summary, contents, headers, etc. [10%]

Task

Task

- Your task is to **design** an intelligent interactive system, identify a suitable **need**, demonstrate that it **fulfills a need**, show an awareness of **user-centred design**, identify the **requirements** of the design, detail the design process of the intelligent interactive system up to the **conceptual design** and **product architecture** stage, ensure the device is **safe** by conducting a **risk analysis** and finally describe how the device is (or can be) **verified** and **validated**
- Your design needs to be **evidence-based** (**not** dreaming up a hypothetical system which is impossible to make)
- Your design is **conceptual** in nature—this is a module teaching you a design process, it is **not** a module that teaches you how to realise the design

- **IMPORTANT: Document your progress throughout, it will help you immensely when writing your report**

Problem context and solution-neutral problem statement

- **Verification** is the process of ensuring a device meets all requirements, specified in a requirements document
  - "Are we building the thing right?"
- **Validation** is the process of ensuring the device is able to solve the user's problems
  - "Are we building the **right** thing?"
- **Problem context** is a narrative that situates the target audience (intended users) in appropriate situations trying to achieve appropriate objectives
- From the problem context we can arrive at a **problem statement**, which our intelligent interactive system can solve
  - A design can have many problem statements, though I recommend focussing on a single one
  - To allow a **wide search** of design options it is **vital** to arrive at a **solution-neutral problem statement** at the correct level of abstraction
  - A solution-neutral problem statement formulates a problem statement in solution-neutral terms, thereby enlarging the design search space

A simplified design process

- Identify problem context
- Devise solution-neutral problem statement
- Begin eliciting requirements, primarily user requirements
- Carry out functional analysis (identify function structures)
- Conceptual design
- Feed knowledge of function structures and translation of functions to function carriers to updated requirements specification
- Embodiment design
- Detailed design
- Verification
- Validation
- (Manufacturing) *if applicable*
- Support
- (Disposal) *if applicable*

For the next lecture

- Search the news, the research literature, the professional literature (specialist magazines) and/or just use your creativity to come up with a proposal for an intelligent interactive system
- Prepare a 1-minute presentation of your progress to the entire class
  - In your presentation (which will be **timed** and must be **very brief**) you should present:
  1. The problem domain/context and the actual problem
  2. A solution-neutral problem statement (see handout on the Moodle site on how to achieve this)
- You should ensure you **read extensively** about your problem domain and you should be aware that copying an existing intelligent interactive system for a known problem is likely to result in an **unimpressive** final report. You should also be aware of the department's **plagiarism** policy, the department treats plagiarism very, very seriously.
- However, your problem does not need to be completely original. A good problem is realistic and can be solved **with today's knowledge**
- Remember that by setting the problem you are implicitly simultaneously the client and the engineer. Therefore, ensure it will be actually feasible to design a solution.
- After the next lecture, **I will take the role of the client and I will be throughout this module probing you about your design and question how it solves *my* needs**

Uncertain Interaction

An Introduction

Visions of the Future

- Ubiquitous sensing
  - Smart home, Internet of Things, etc.
- Pervasive agents
  - Spoken dialogue-based command and query interfaces
- Virtual reality
  - Portable office, training, immersive data analytics
- Phone without a phone
  - Optical see-through head-mounted displays with form factors comparable to everyday glasses

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All assume fluid interfaces based on fundamentally **uncertain** interaction

Classic human-computer interaction (HCI) design strategies are not fit for purpose

Classic HCI assumptions

- The pixel space is controlled (fully defined by a display)
- User intention is sensed precisely and without noise (mouse, keyboard, touchscreen)

New challenges

- There is no pixel space or it is context-dependent
- User intention must be inferred and sensing is inherently noisy

Classic human-computer interaction (HCI) design strategies are not fit for purpose

Classic HCI assumptions

- The pixel space is controlled (fully defined by a display)
- [illegible] sensed precisely and without noise (mouse, keyboard, touchscreen)

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The era of “easy HCI” is over

Classic human-computer interaction (HCI) design strategies are not fit for purpose

Classic HCI assumptions

- The pixel space is controlled (fully defined by a display)
- Input can be sensed precisely and without noise (mouse, keyboard, touchscreen)

New challenges

- There is no pixel space or it is context-dependent
- Input must be inferred and sensing is inherently noisy

We need new design methods for probabilistic user interfaces

Why model-driven HCI is necessary for progress

The tragicomic story of supporting text entry on a smart watch

Example: typing on a smartwatch

- Small screen size is obviously a constraint
- Many naïve solutions:
  - Progressive zooming techniques
  - Reduce keyset (á la the old telephone keypad techniques)
  - Various multi-stroke strategies
- **All slow**
- **All demand user learning** (no immediate efficacy)

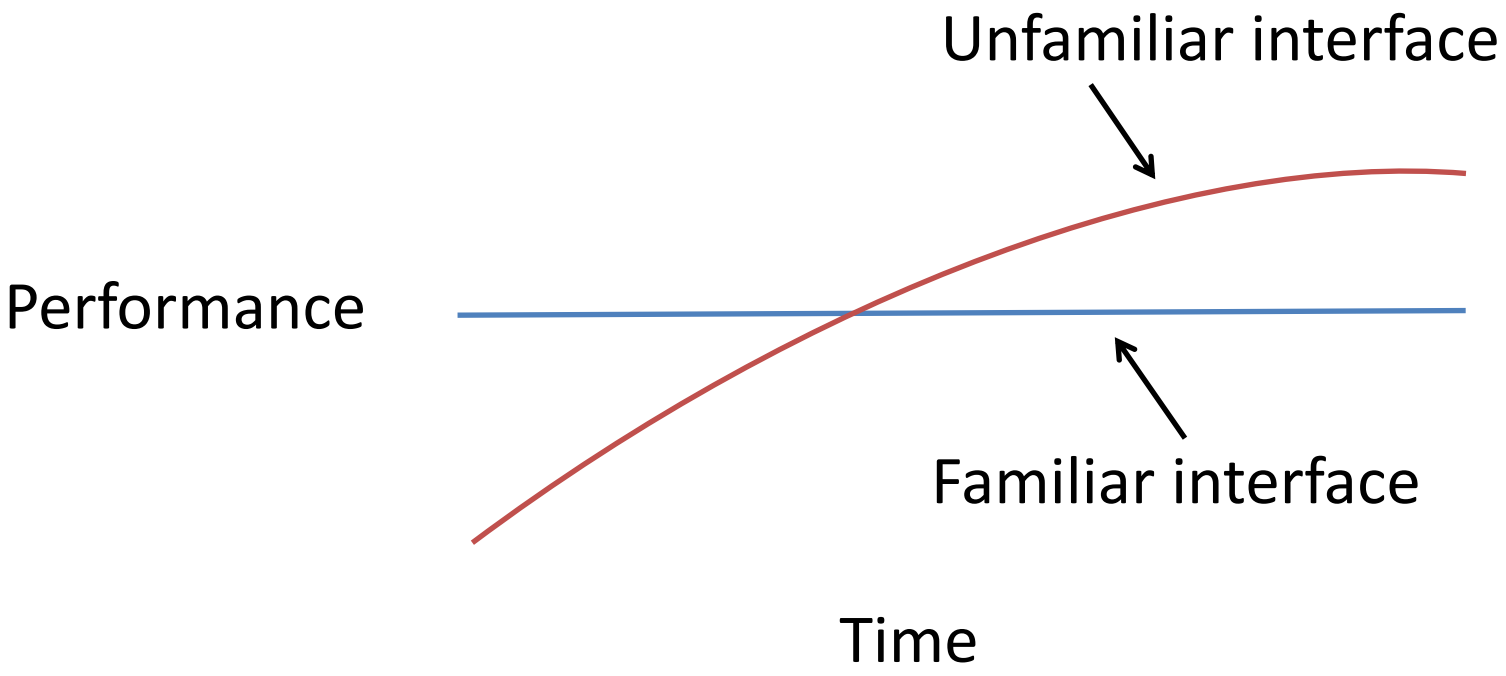
The cross-over point

Performance

Time

The cross-over point

The cross-over point



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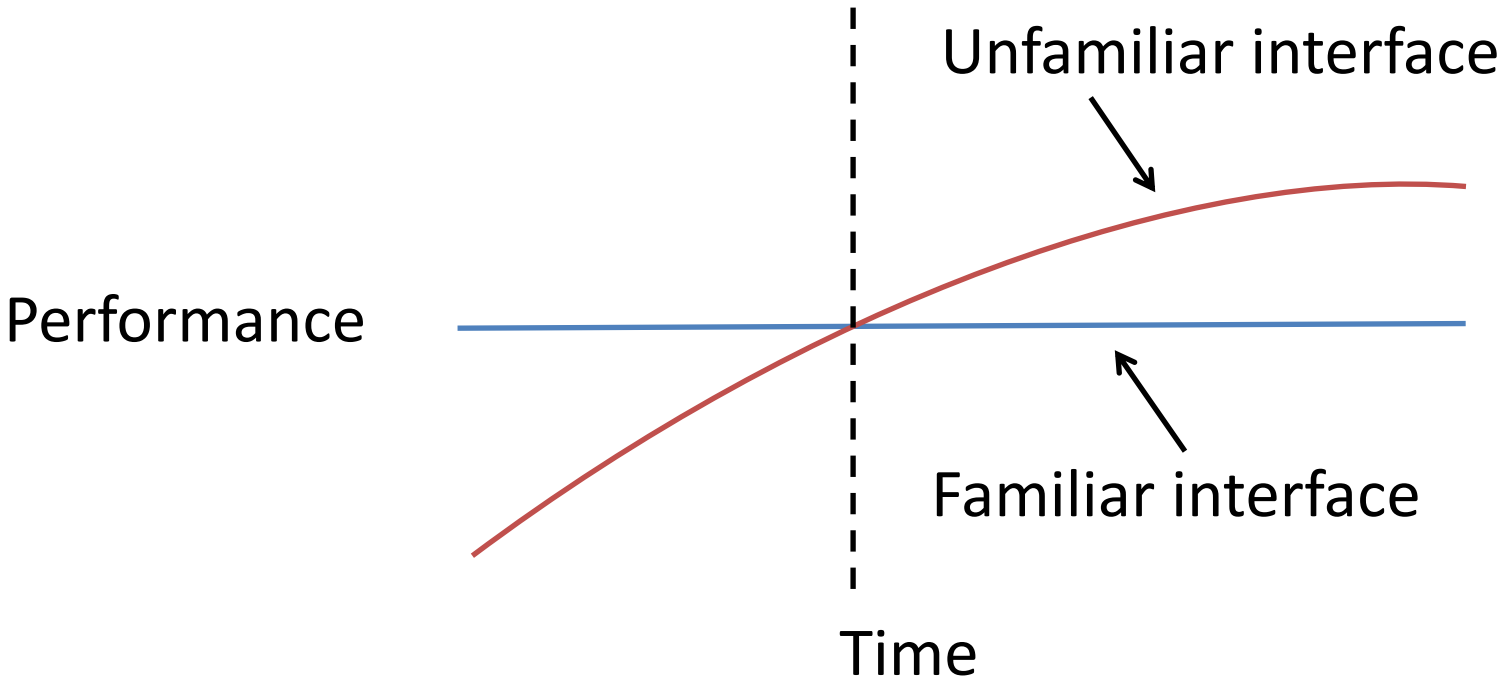

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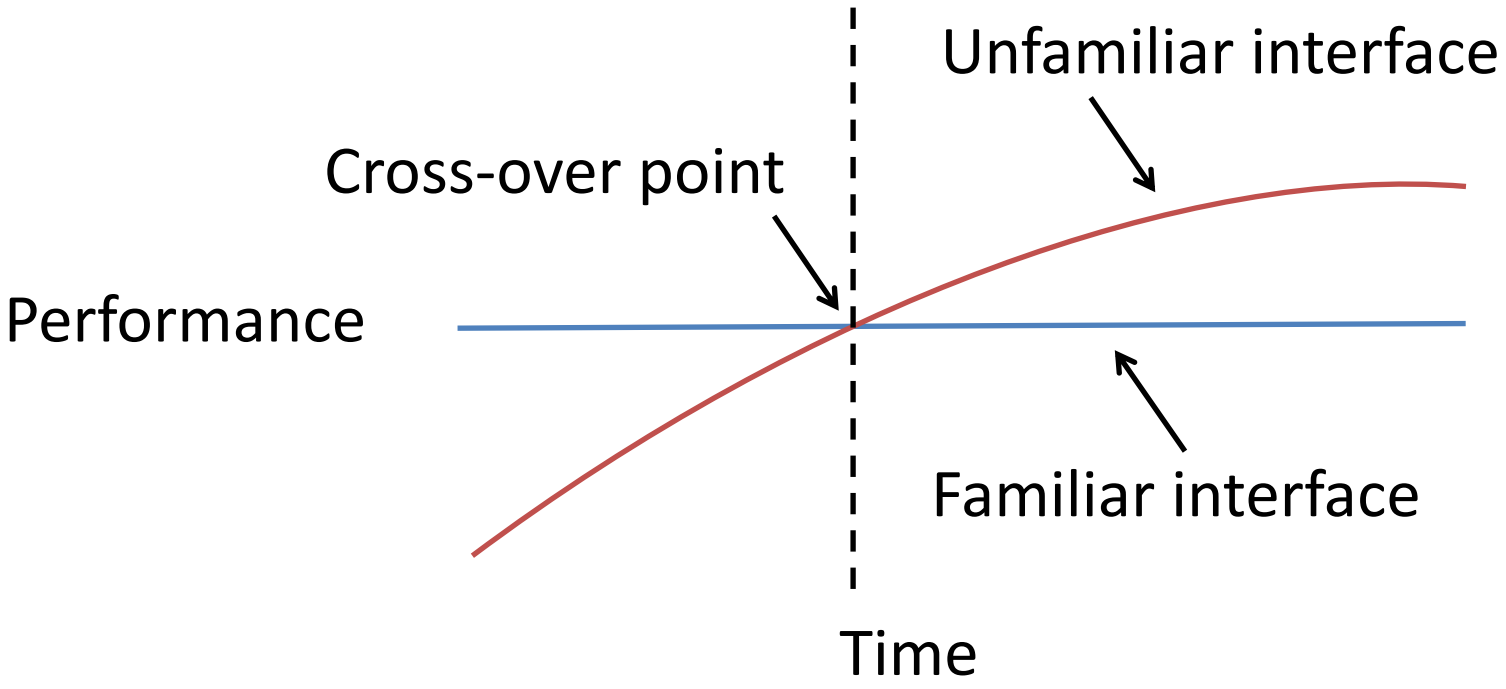

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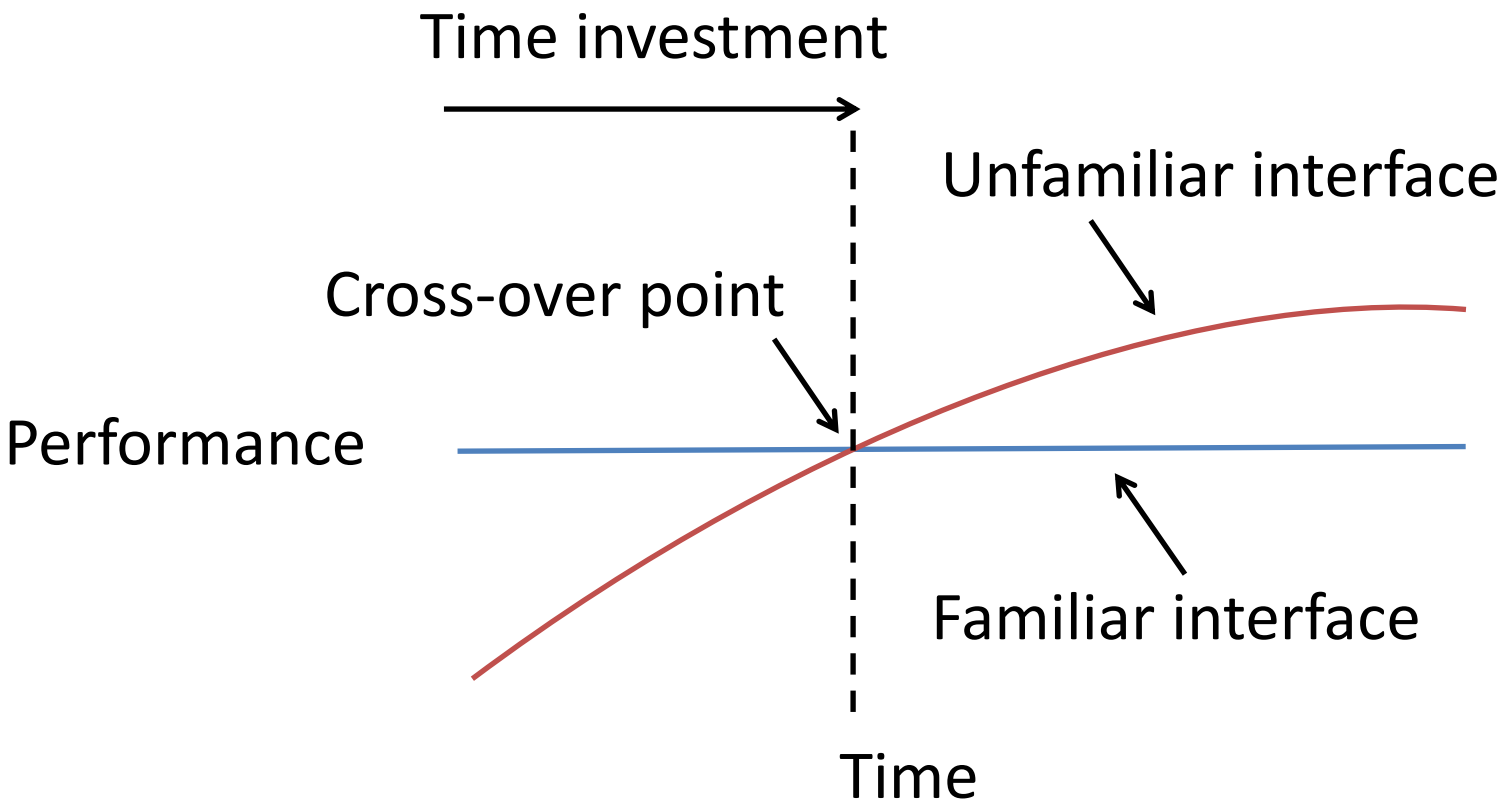

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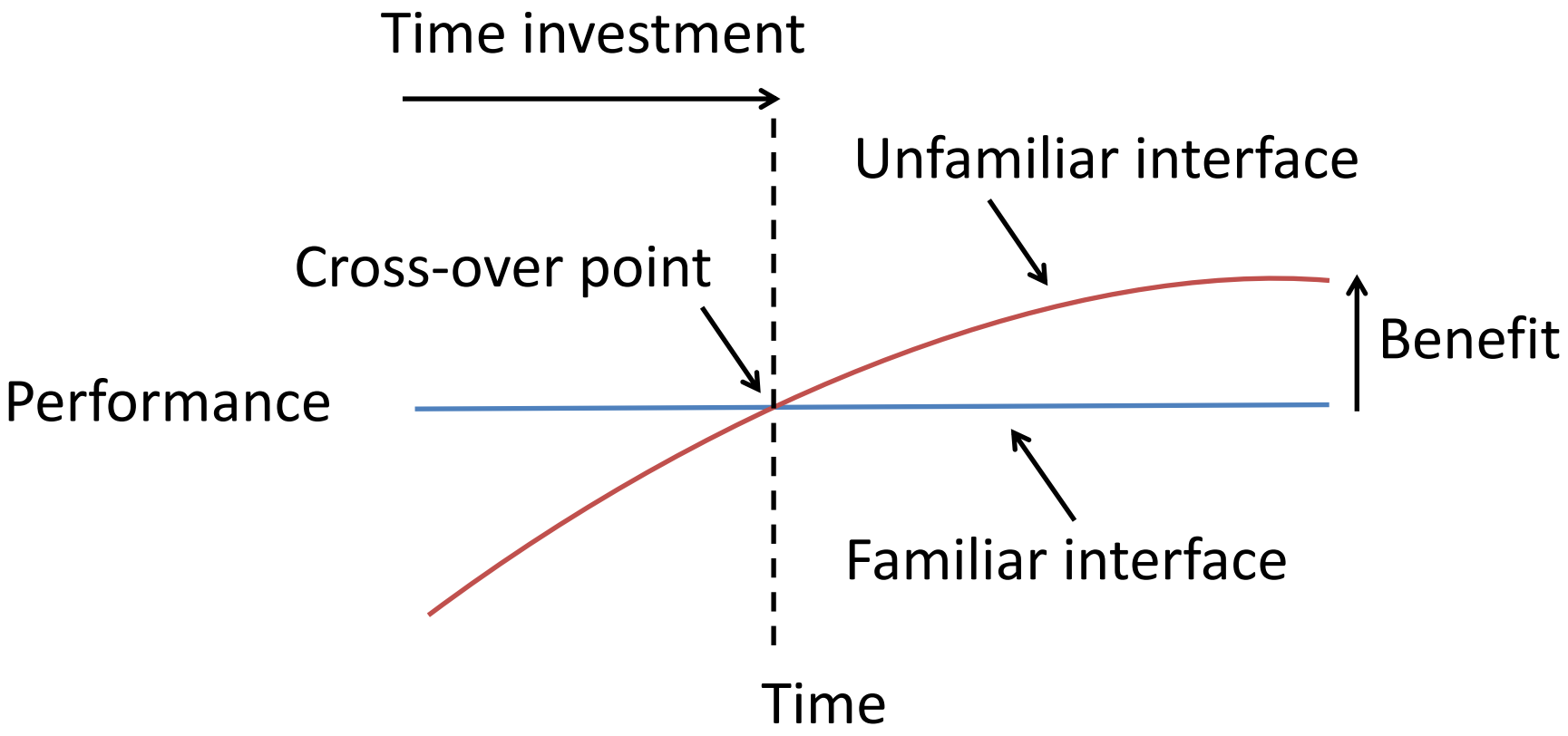

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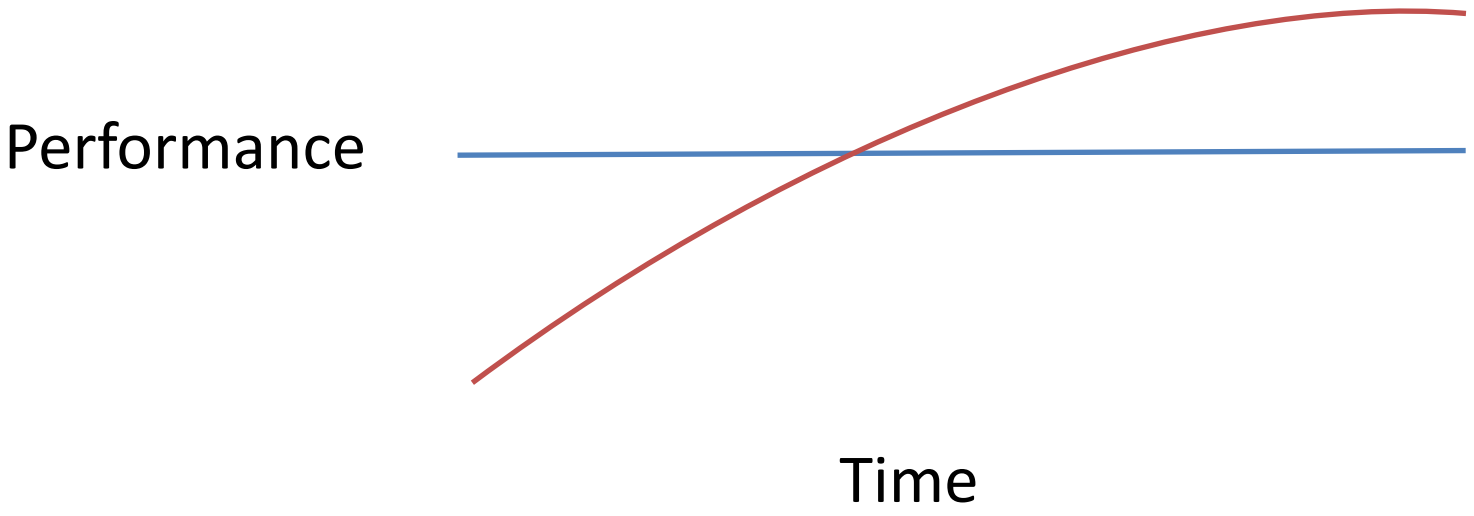

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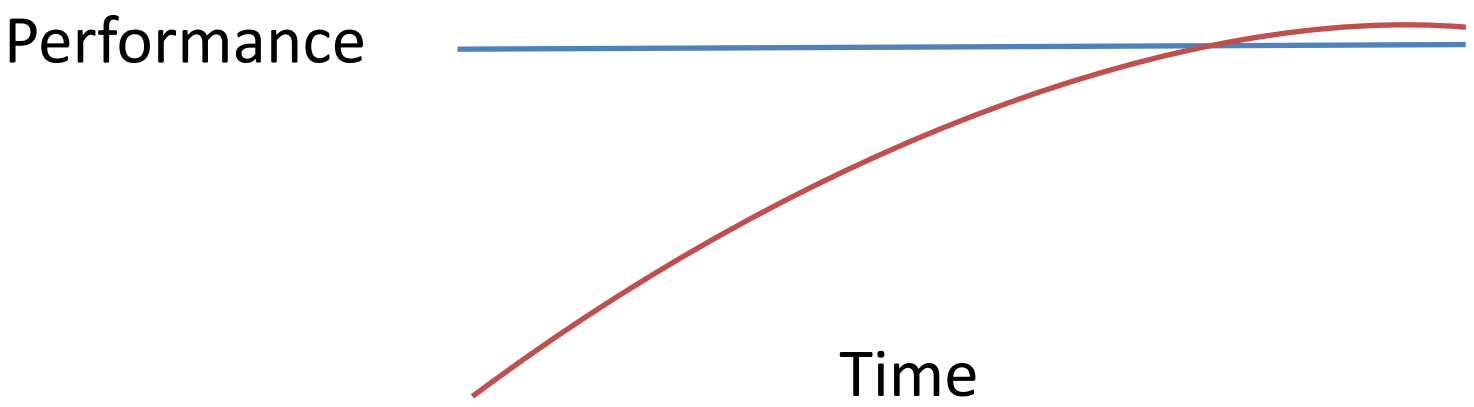

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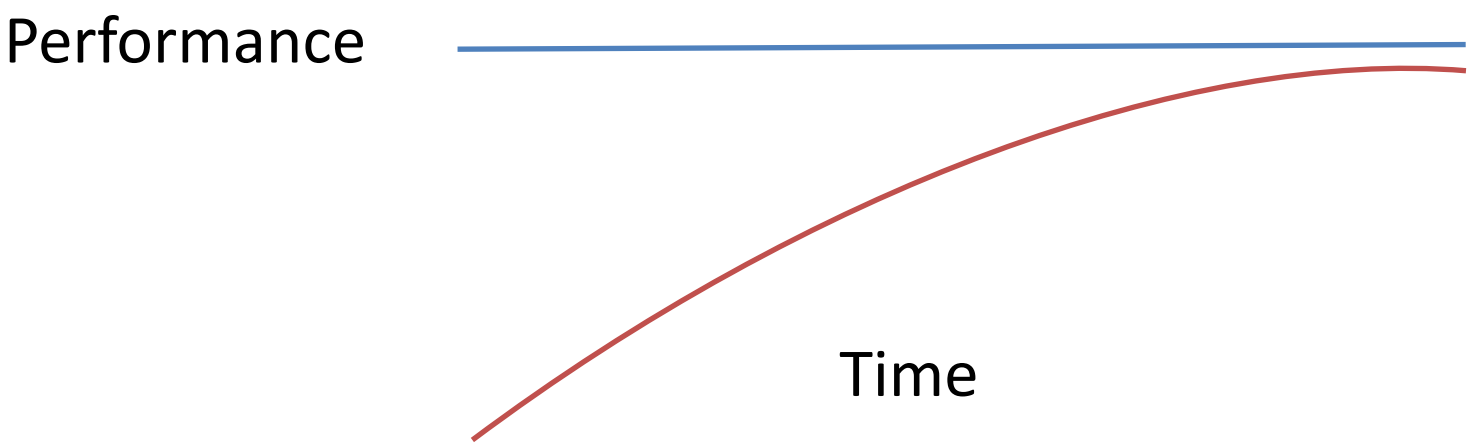
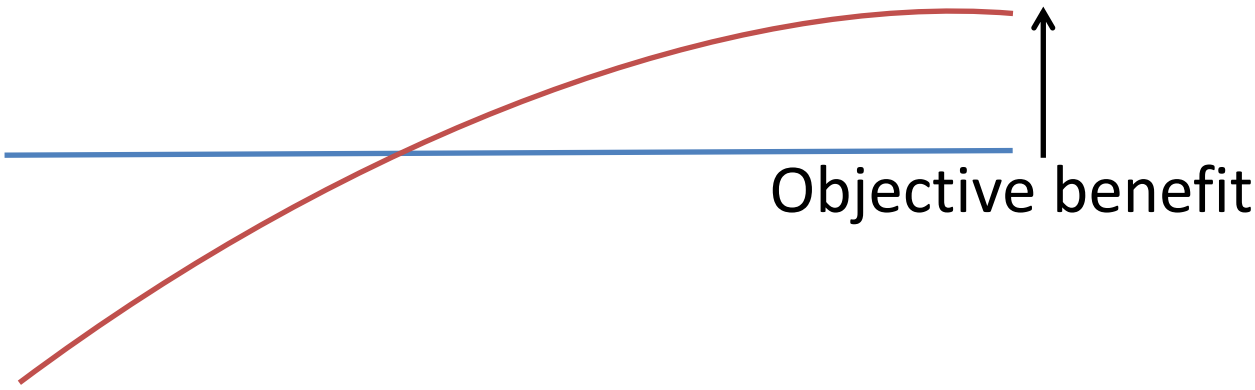
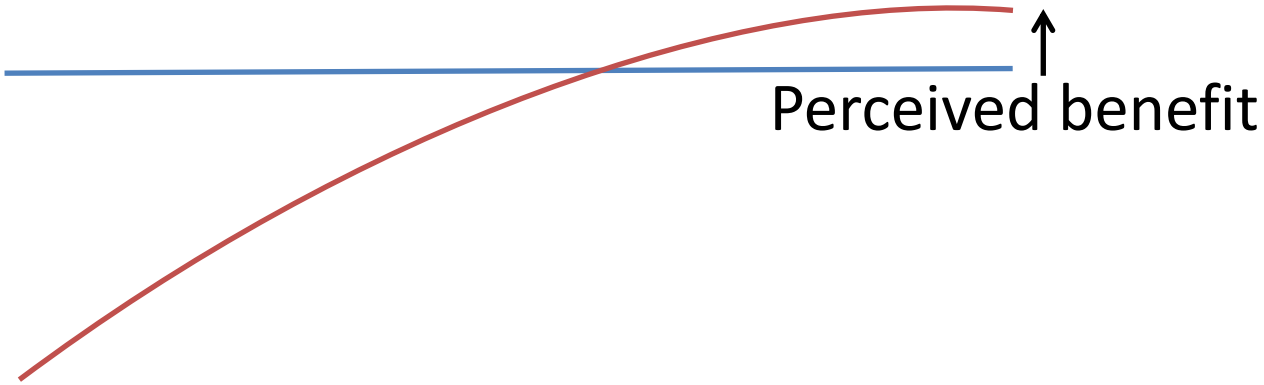


The cross-over point



Nicosia, M., Oulasvirta, A. and Kristensson, P.O. 2014. Modeling the perception of user performance. In *Proceedings of the 32nd ACM Conference on Human Factors in Computing Systems (CHI 2014)*. ACM Press: 1747-1756.

The cross-over point



Nicosia, M., Oulasvirta, A. and Kristensson, P.O. 2014. Modeling the perception of user performance. In *Proceedings of the 32nd ACM Conference on Human Factors in Computing Systems (CHI 2014)*. ACM Press: 1747-1756.

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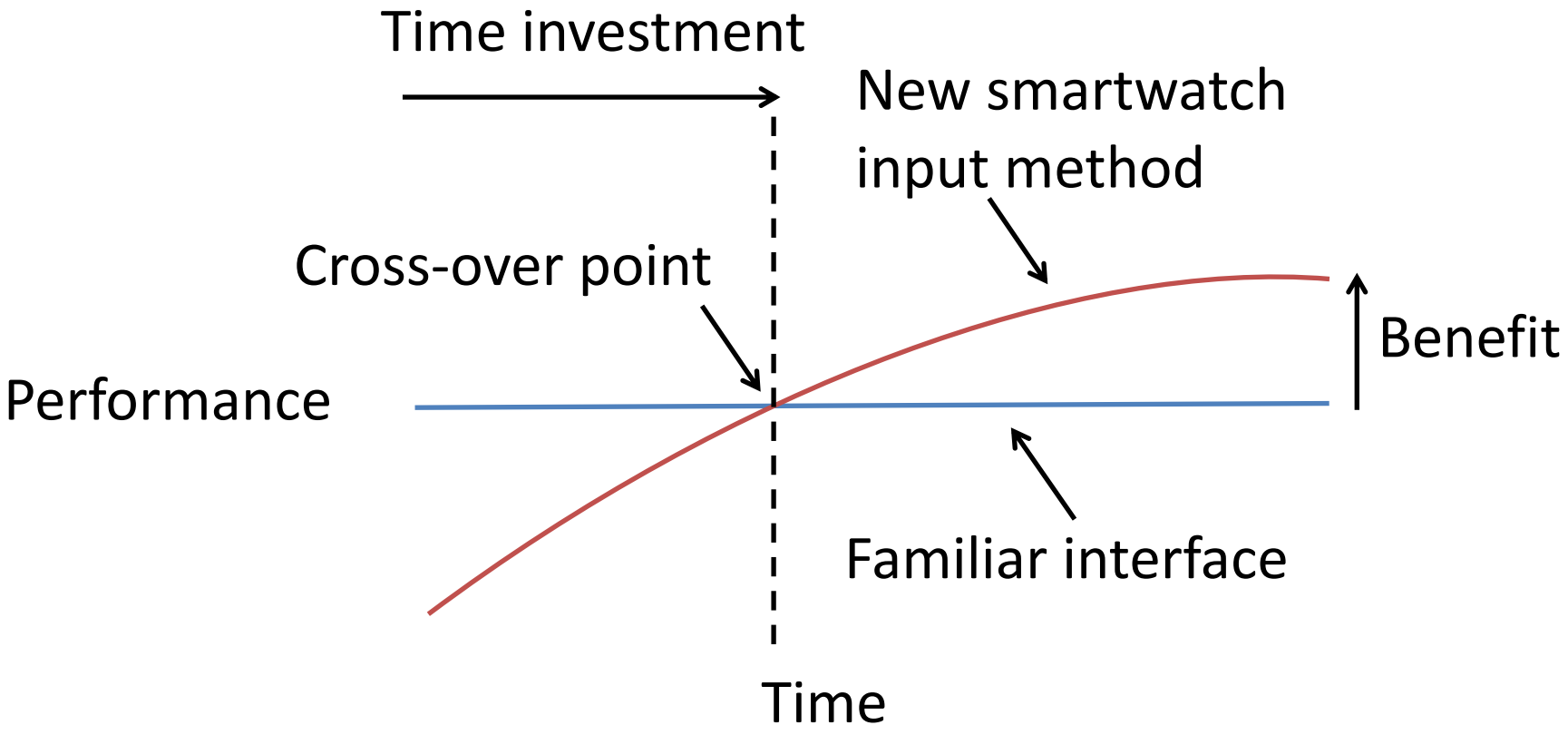
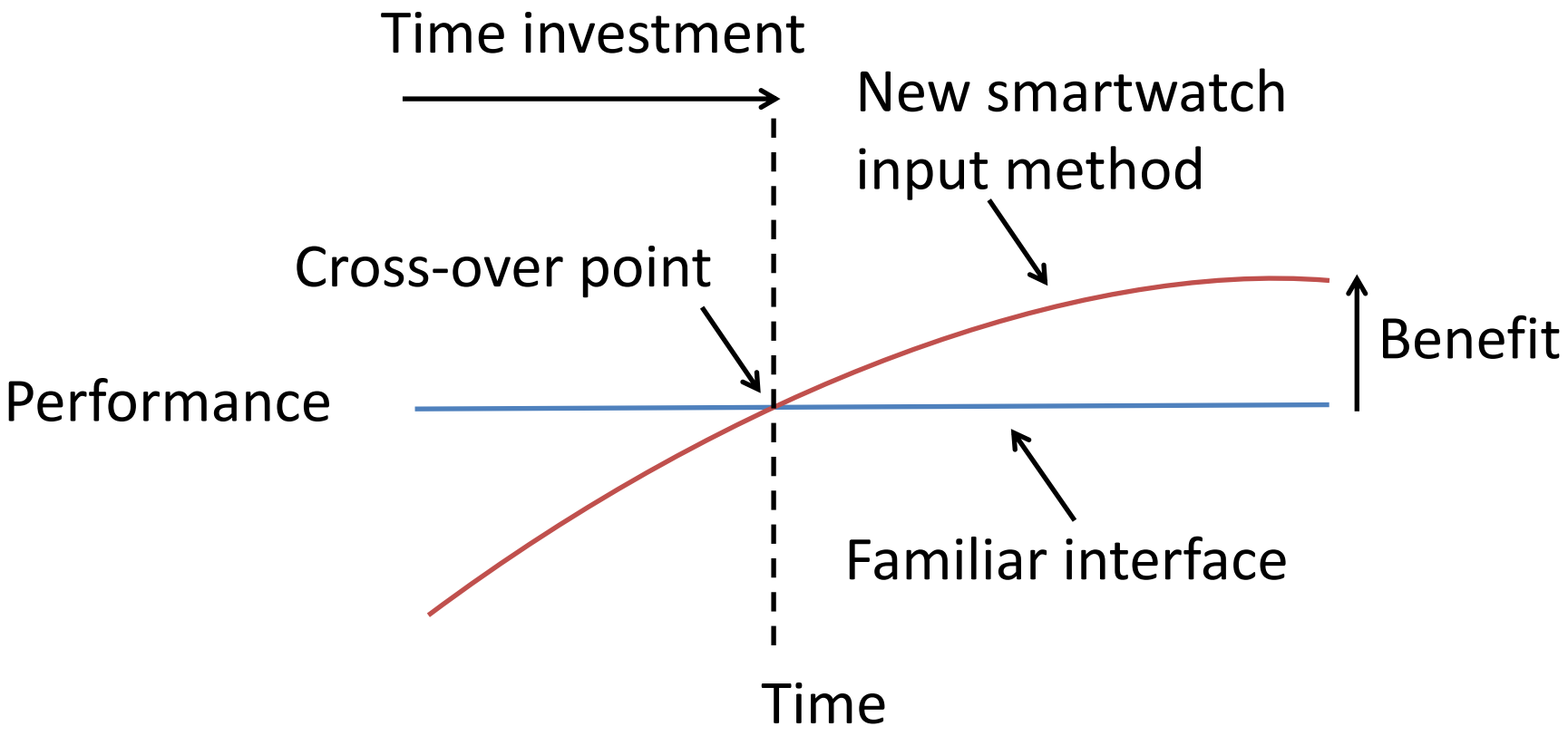


The cross-over point

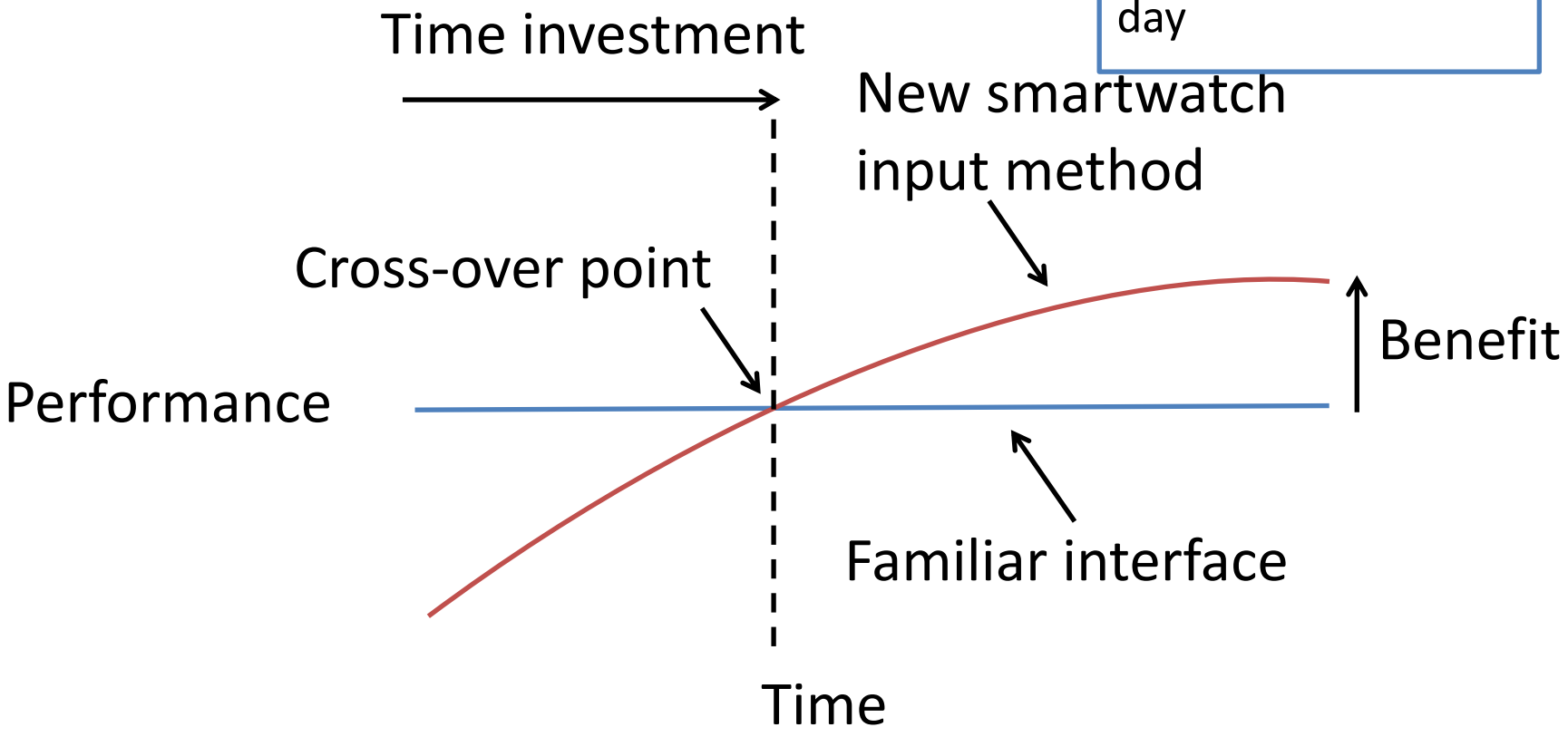
= 40 hours of **dedicated** practice



The cross-over point

= 40 hours of **dedicated** practice

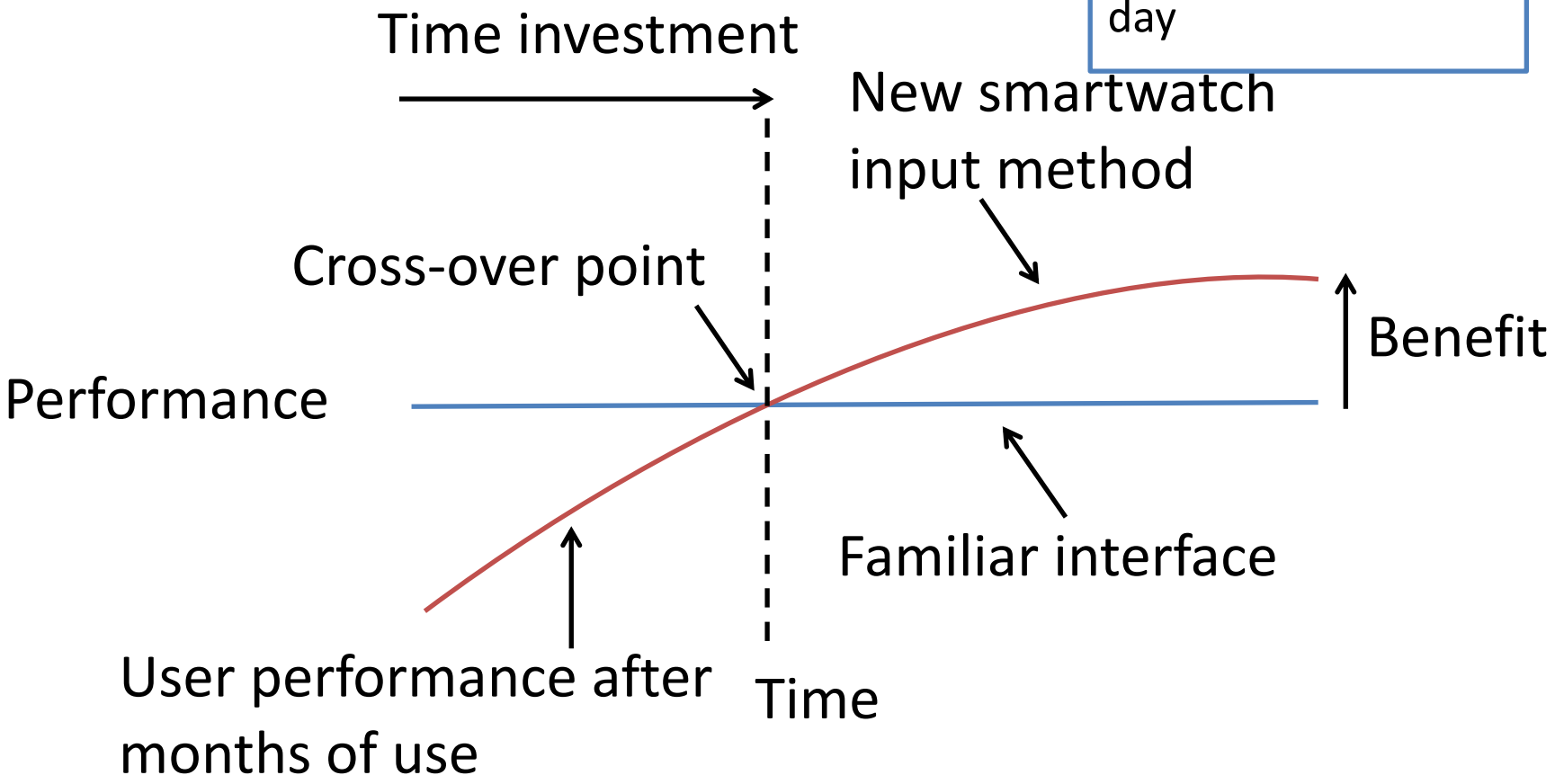
Assume the user types for five minutes on their smartwatch every day



The cross-over point

Assume the user types for five minutes on their smartwatch every day

= 40 hours of **dedicated** practice



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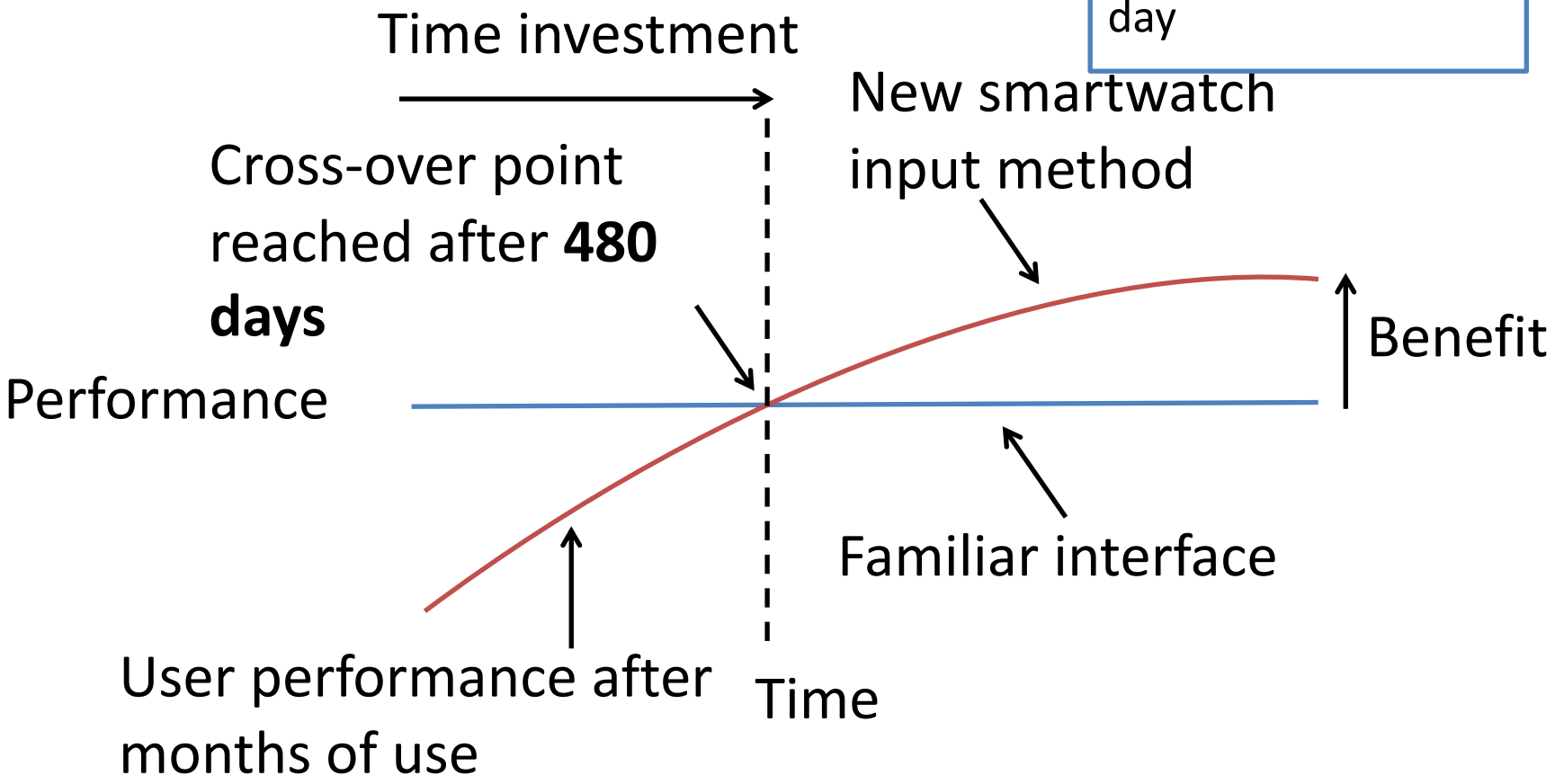
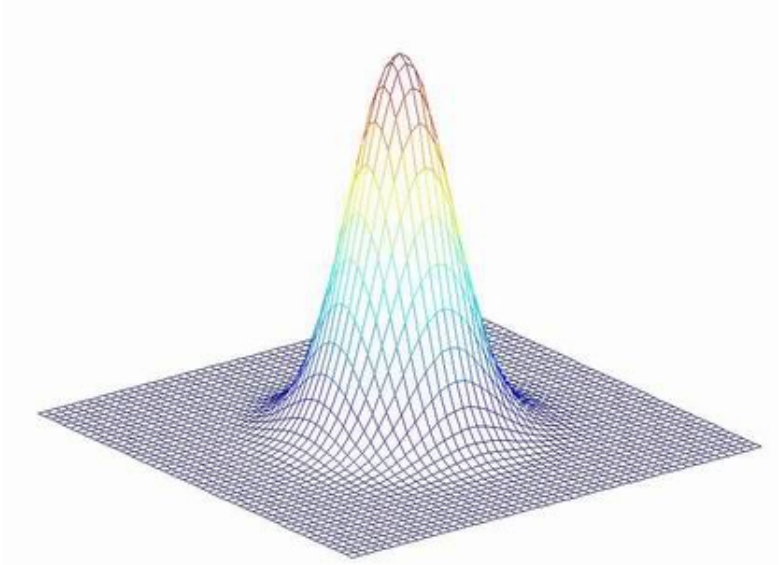


Touch modelling



2D Gaussians centered at each key.
Separate variances in the x- and y-dimensions.

$$P(Letters|Taps) \propto \underbrace{P(Taps|Letters)}_{\text{touch model}} \underbrace{P(Letters)}_{\text{language model}}$$

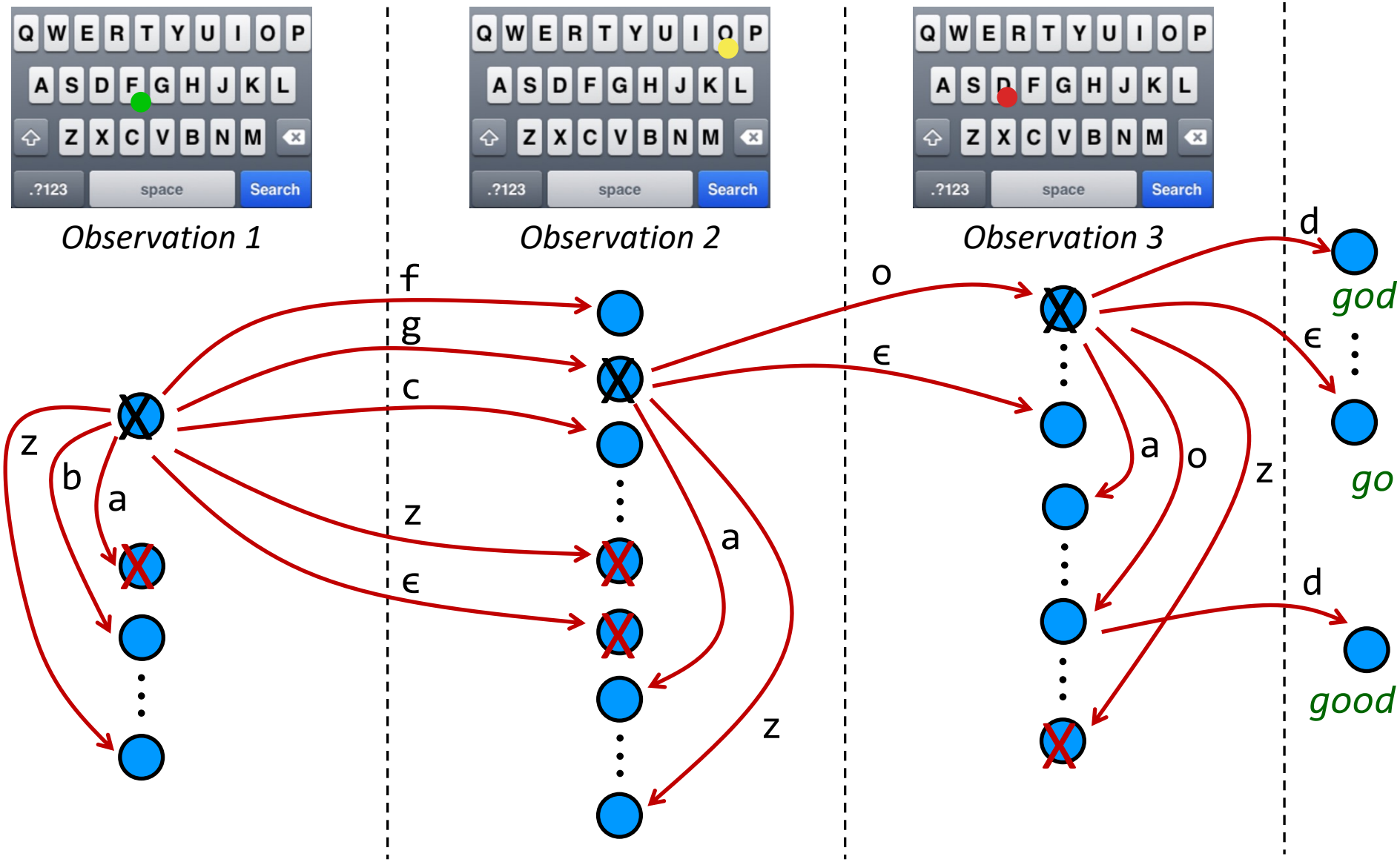
Vertanen, K., Memmi, H., Emge, J., Reyal, S. and Kristensson, P.O. 2015. VelociTap: investigating fast mobile text entry using sentence-based decoding of touchscreen keyboard input. *In Proceedings of the 33rd ACM Conference on Human Factors in Computing Systems (CHI 2015)*. ACM Press: 659-668.

Language modelling

- Language models:
  - **12-gram letter** model
  - **4-gram word** model with unknown word
  - Trained on **billions of words** of data
    - Twitter, blog, social media, Usenet, and web data
  - Optimized for **short email-like messages**
  - Letter + word language model = ~4 GB memory

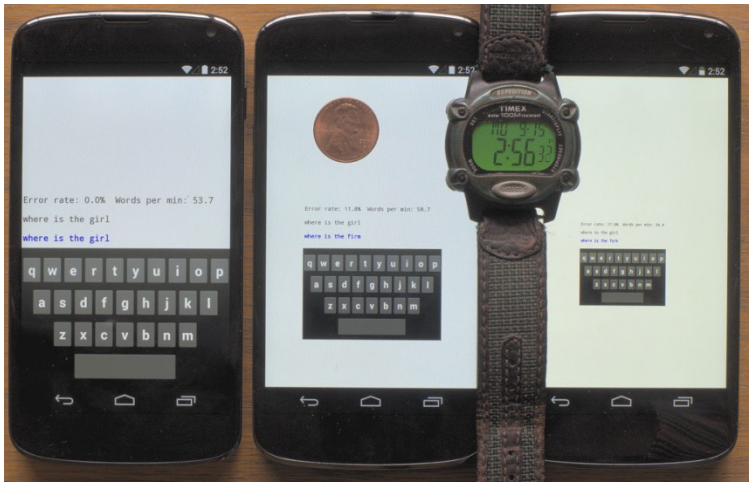
Vertanen, K., Memmi, H., Emge, J., Reyal, S. and Kristensson, P.O. 2015. VelociTap: investigating fast mobile text entry using sentence-based decoding of touchscreen keyboard input. *In Proceedings of the 33rd ACM Conference on Human Factors in Computing Systems (CHI 2015)*. ACM Press: 659-668.

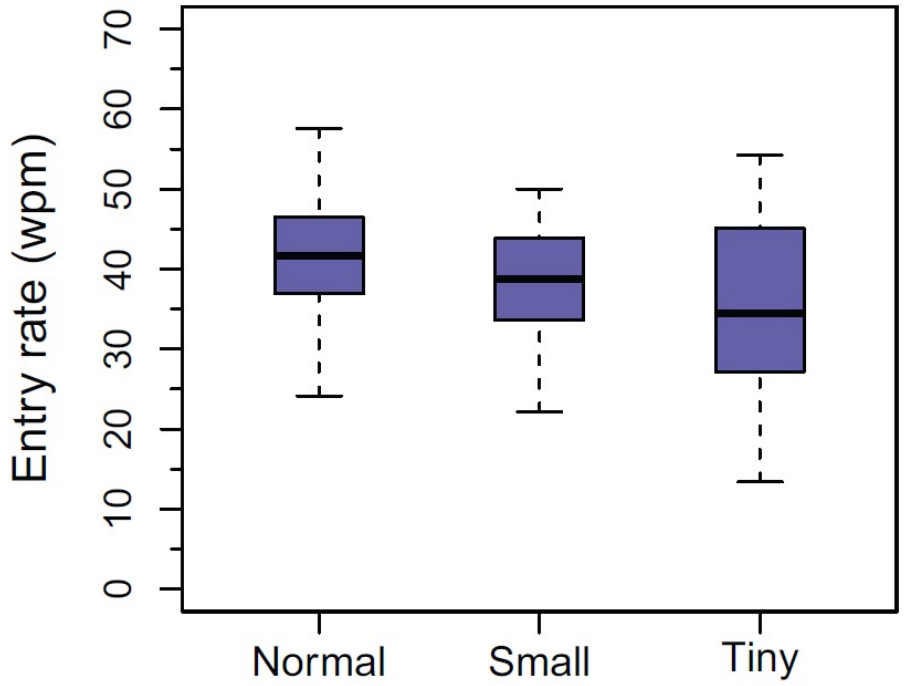
Decoding

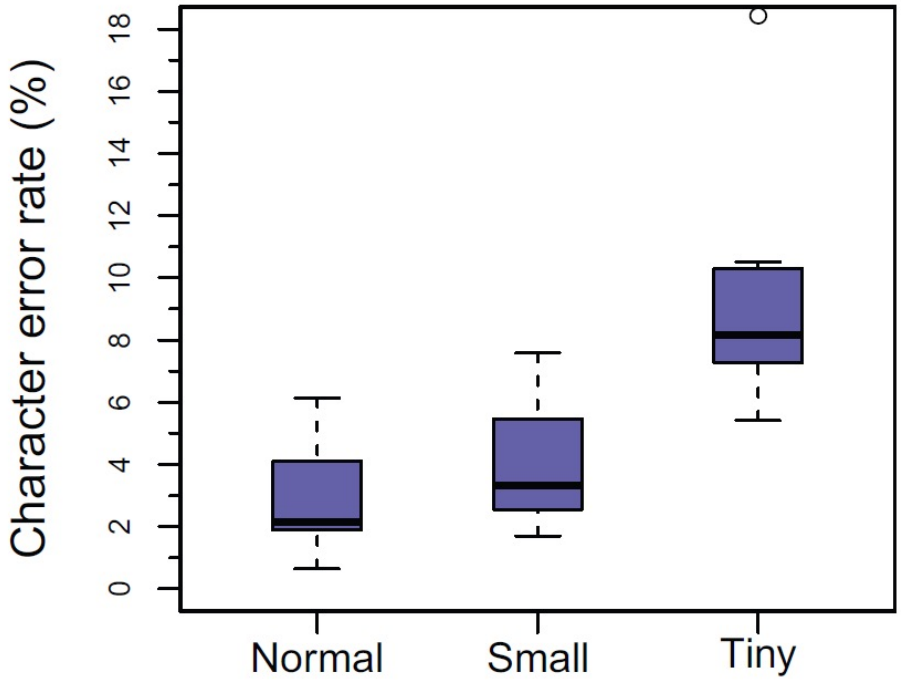

Observation 1
Observation 2
Observation 3
f
g
c
z
ϵ
o
ϵ
z
b
a
a
z
a
o
z
d
god
ϵ
go
d
good
Tokens track: probability, LM context, traceback
Beam prune to keep tractable

Entry and error rate

Condition	
Normal	Standard portrait keyboard, 60mm wide
Small	Big smartwatch, 40mm wide
Tiny	Small smartwatch, 25mm wide

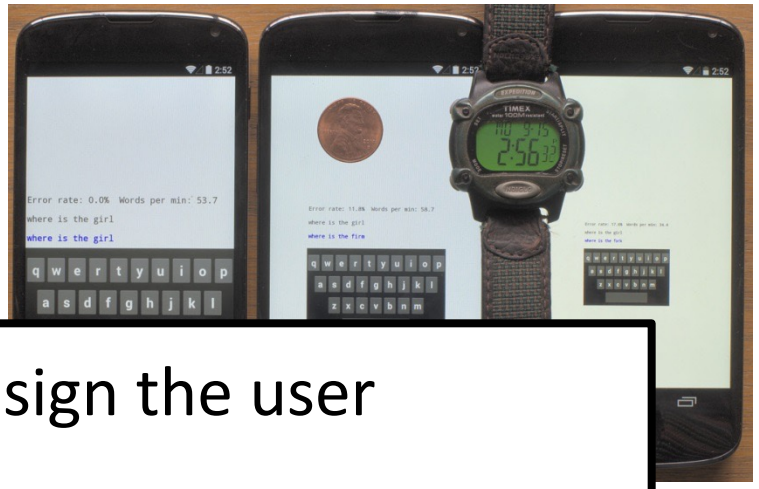




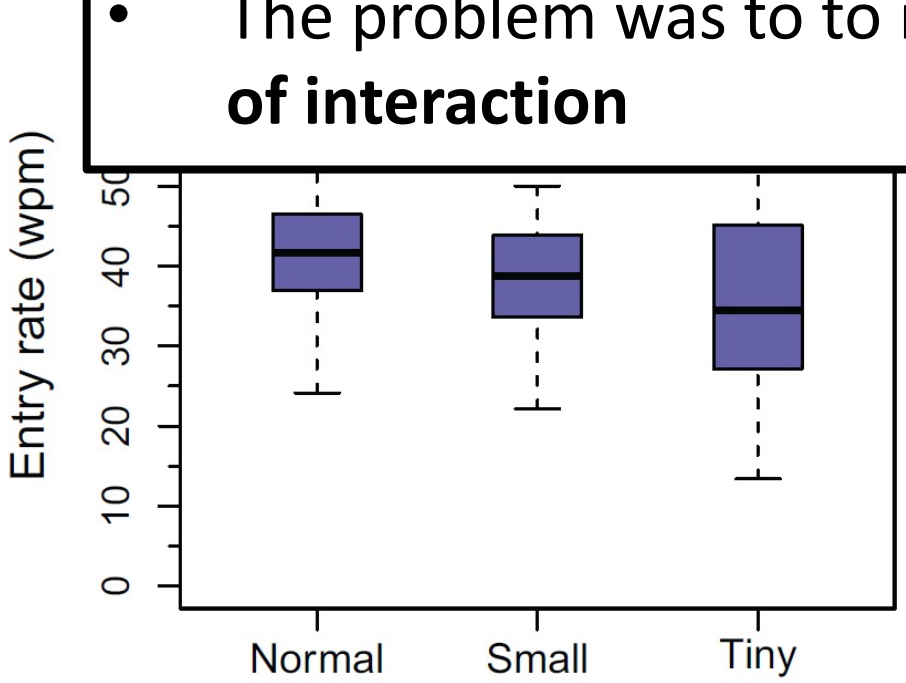


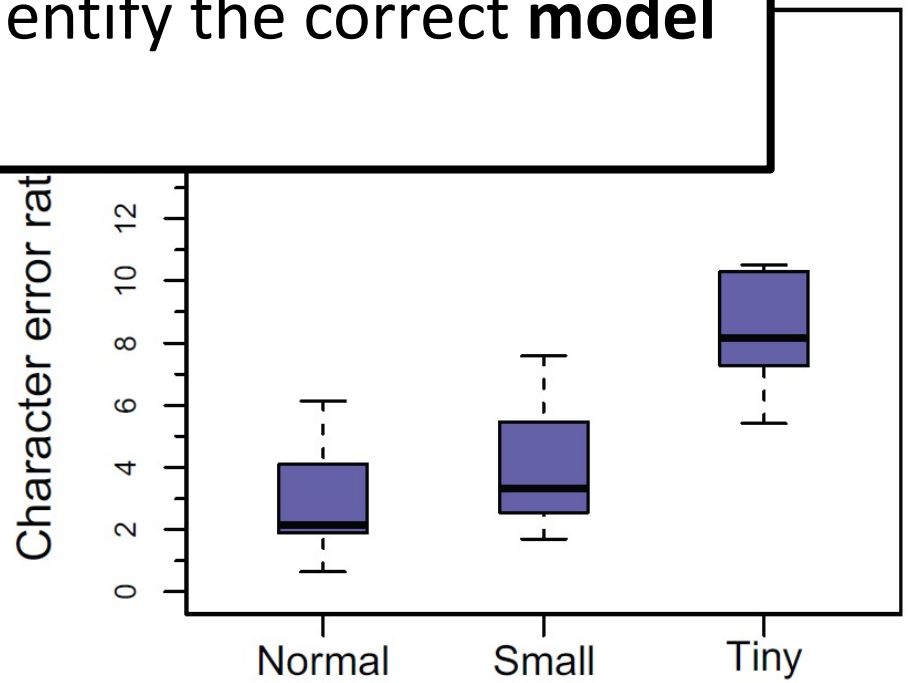
Entry and error rate

Condition	
Normal	Standard portrait keyboard, 60mm wide
Small	Big smartwatch, 40mm wide
Tiny	



- The problem was not to redesign the user interface
- The problem was to to identify the correct **model of interaction**

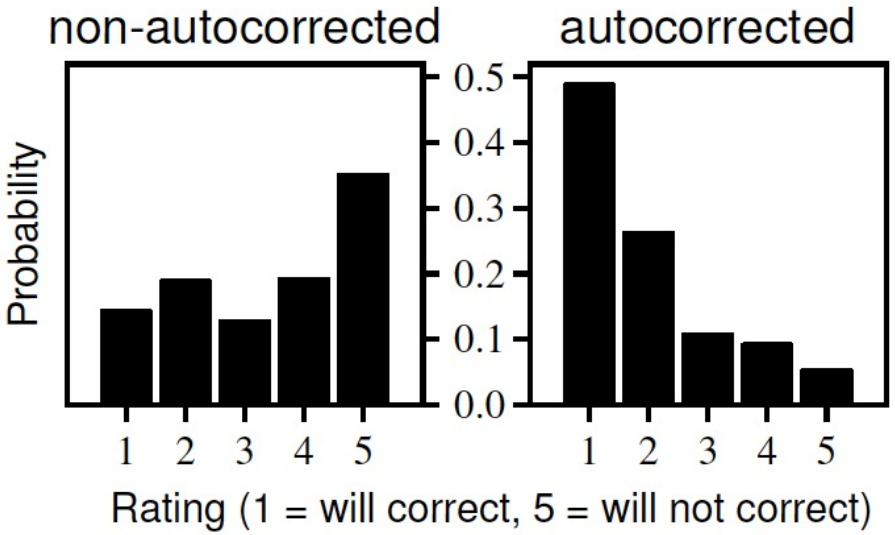




Identifying the correct model of interaction enables *informed* innovation

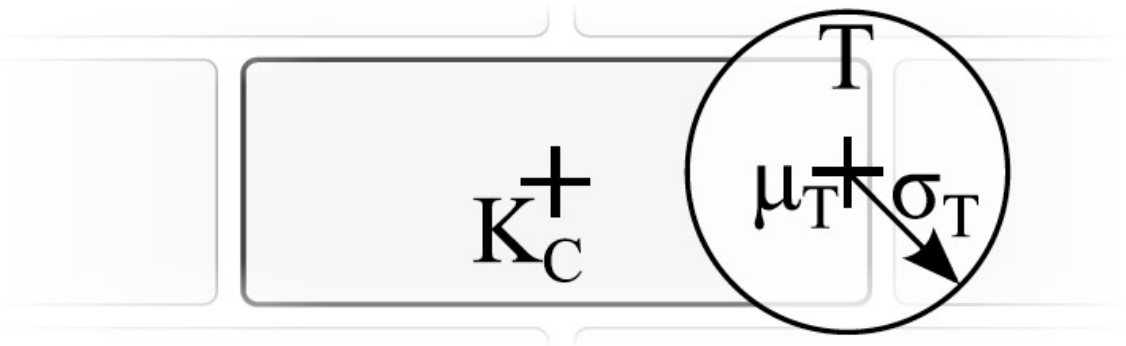
The auto-correct trap

- Auto-correct is great when it works
- However, when auto-correct fails error correction activities exhibit a high penalty
- The solution is to provide users with more **agency** and allow them to regulate their **certainty**



Weir, D., Pohl, H., Rogers, S., Vertanen, K. and Kristensson, P.O. 2014. Uncertain text entry on mobile devices. In *Proceedings of the 32nd ACM Conference on Human Factors in Computing Systems (CHI 2014)*. ACM Press: 2307-2316.

Pressure-sensitive auto-correct

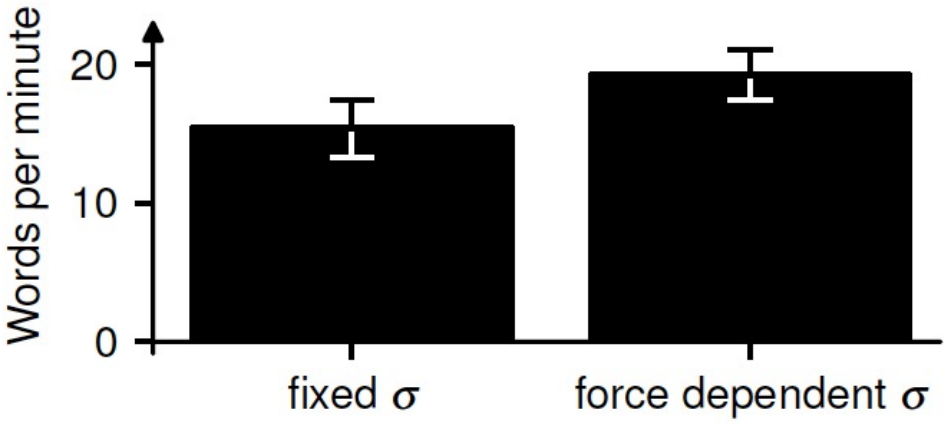


- Likelihood of a Gaussian with standard deviation regulated by pressure
- Standard deviation computed as C/ω_T, where C is a constant and ω_T is the pressure for touch T
- Tuned C so that the pressure of a typical touch had a standard deviation of half a key width

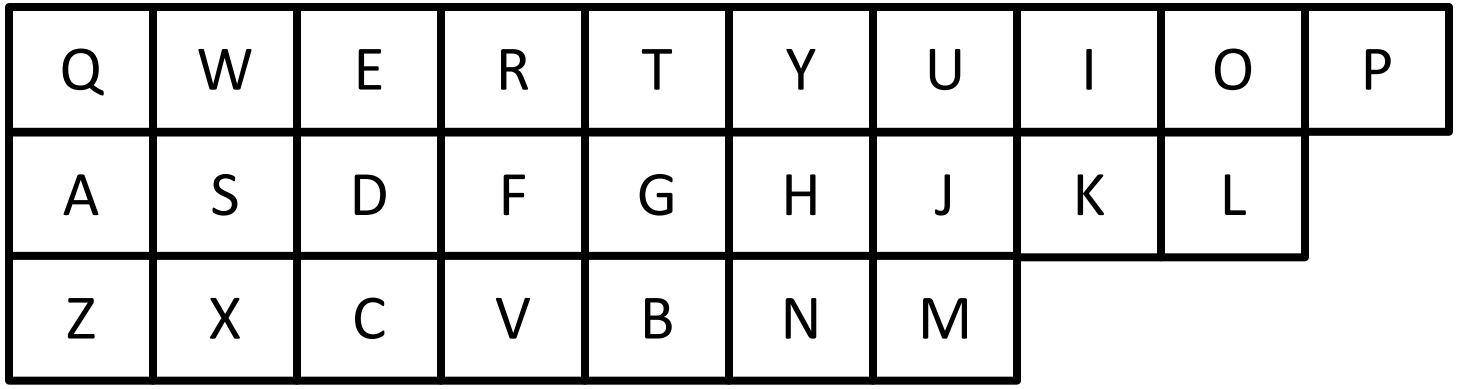
Weir, D., Pohl, H., Rogers, S., Vertanen, K. and Kristensson, P.O. 2014. Uncertain text entry on mobile devices. In *Proceedings of the 32nd ACM Conference on Human Factors in Computing Systems (CHI 2014)*. ACM Press: 2307-2316.

Results

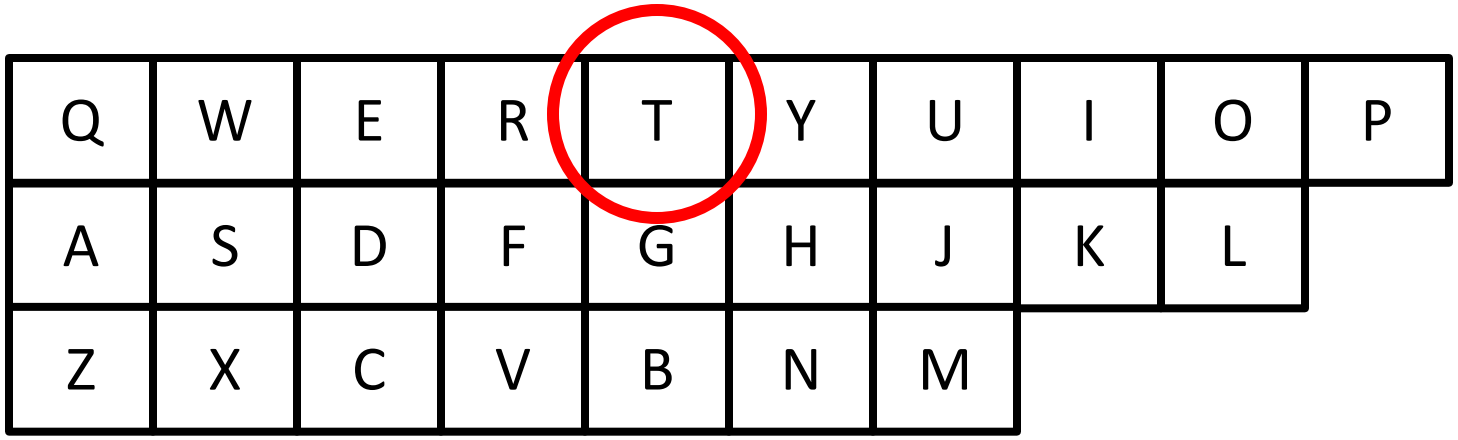
- Enabling users to regulate their certainty by force resulted in a 10% percentage drop in active corrections (fixing a word by backspacing or retyping)
- This improved entry rate by 20%



Eye-typing

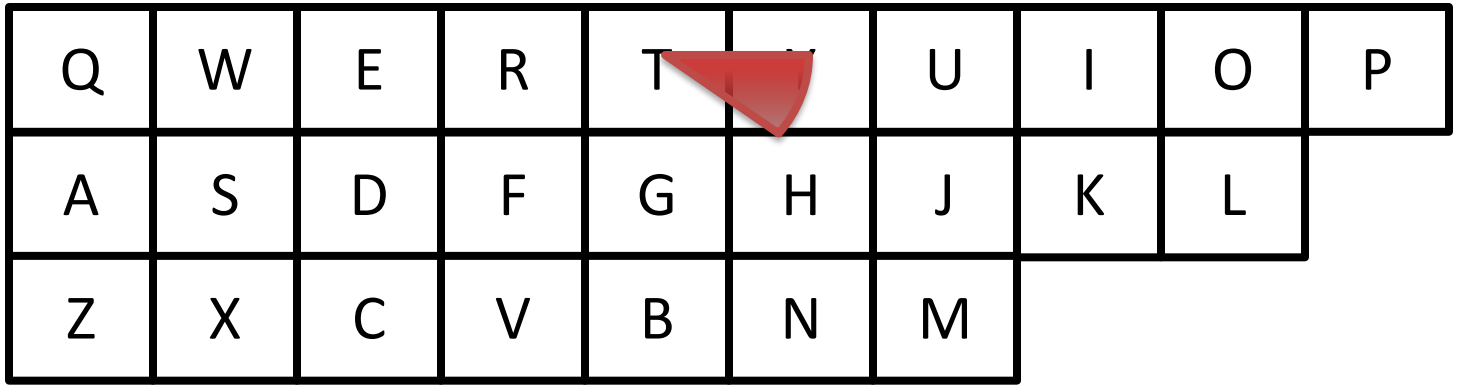


Eye-typing



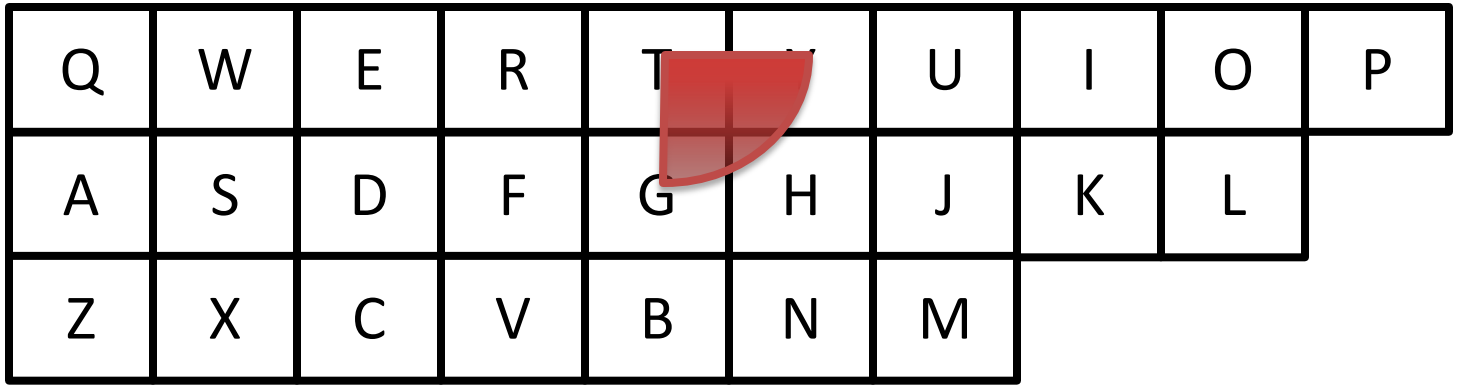
Eye-typing

125 ms



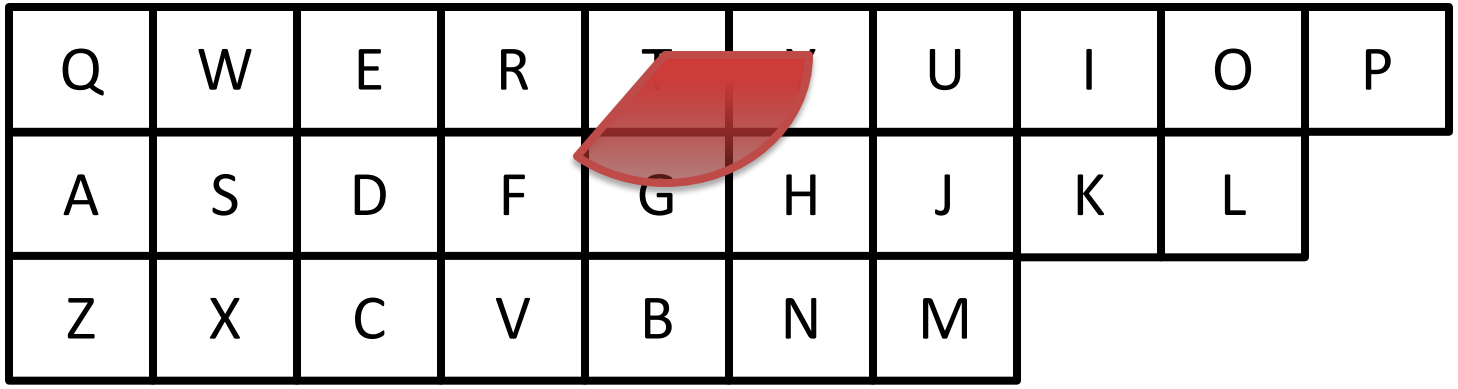
Eye-typing

250 ms



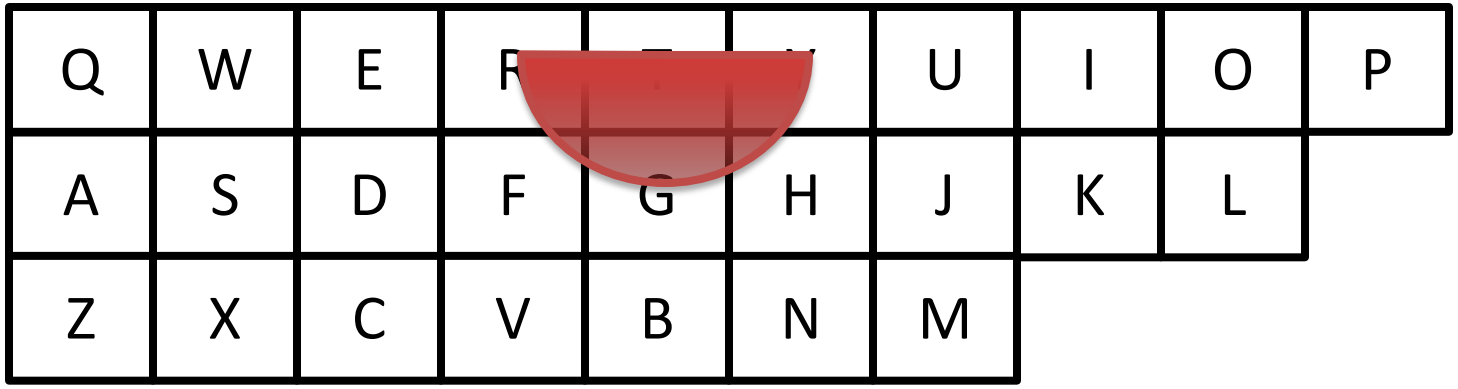
Eye-typing

375 ms



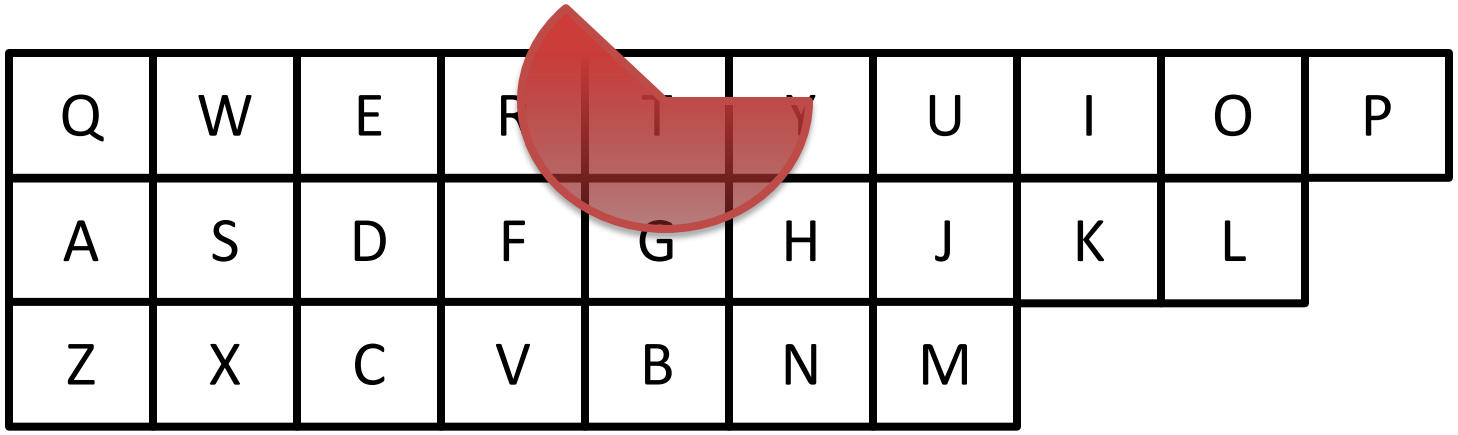
Eye-typing

500 ms



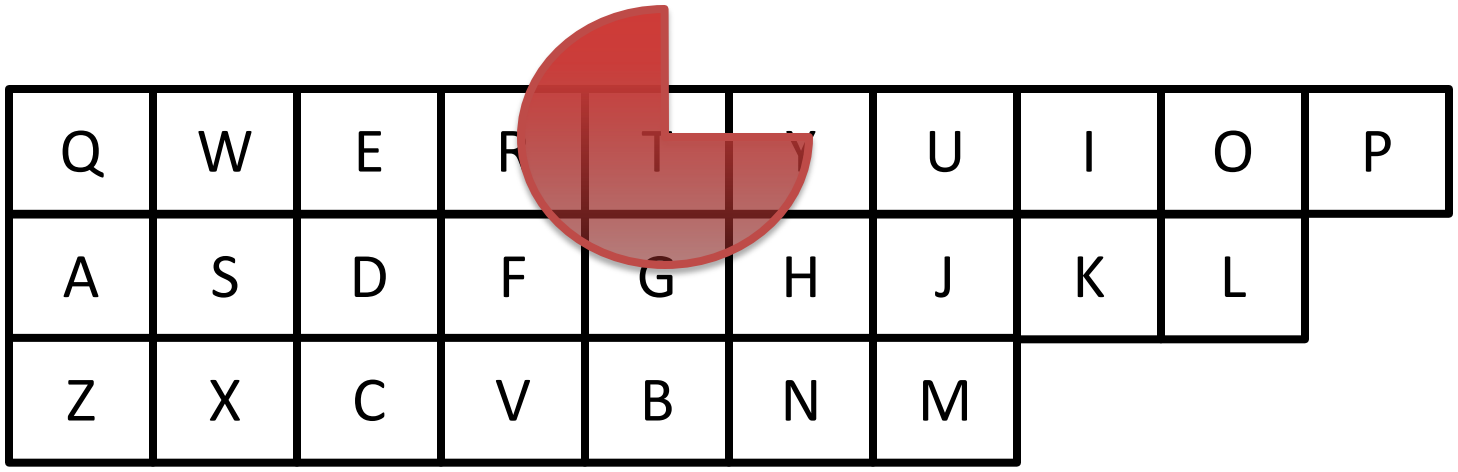
Eye-typing

625 ms



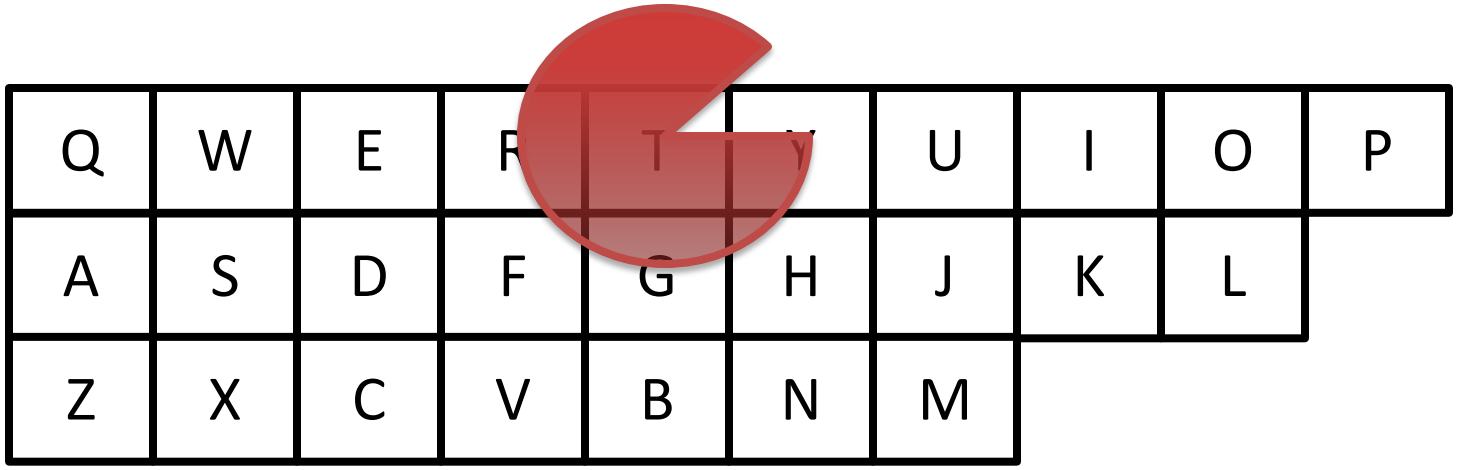
Eye-typing

750 ms



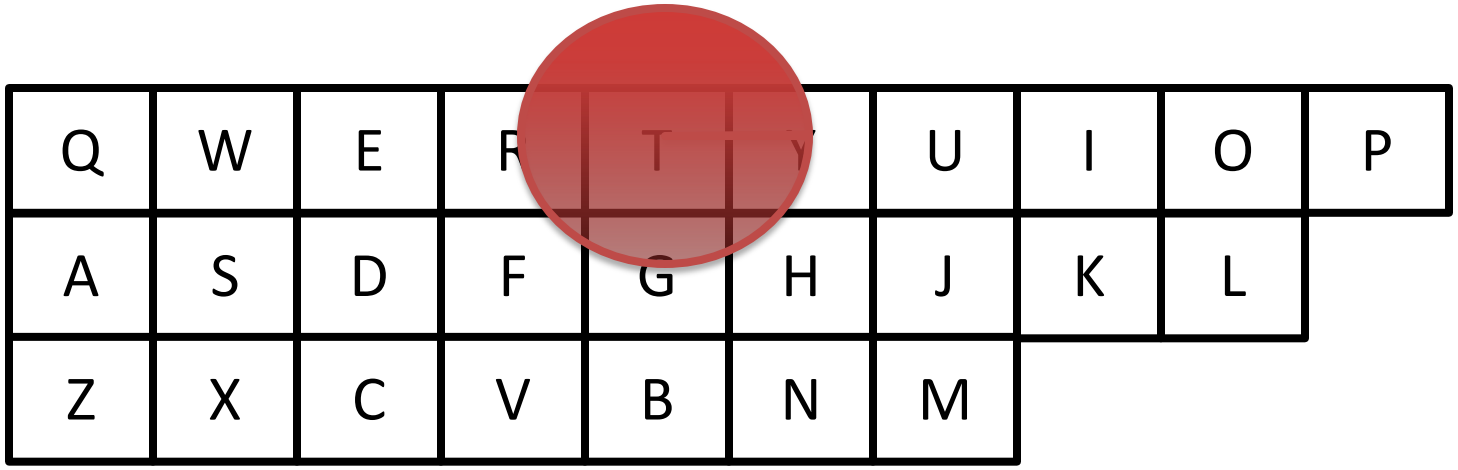
Eye-typing

875 ms



Eye-typing

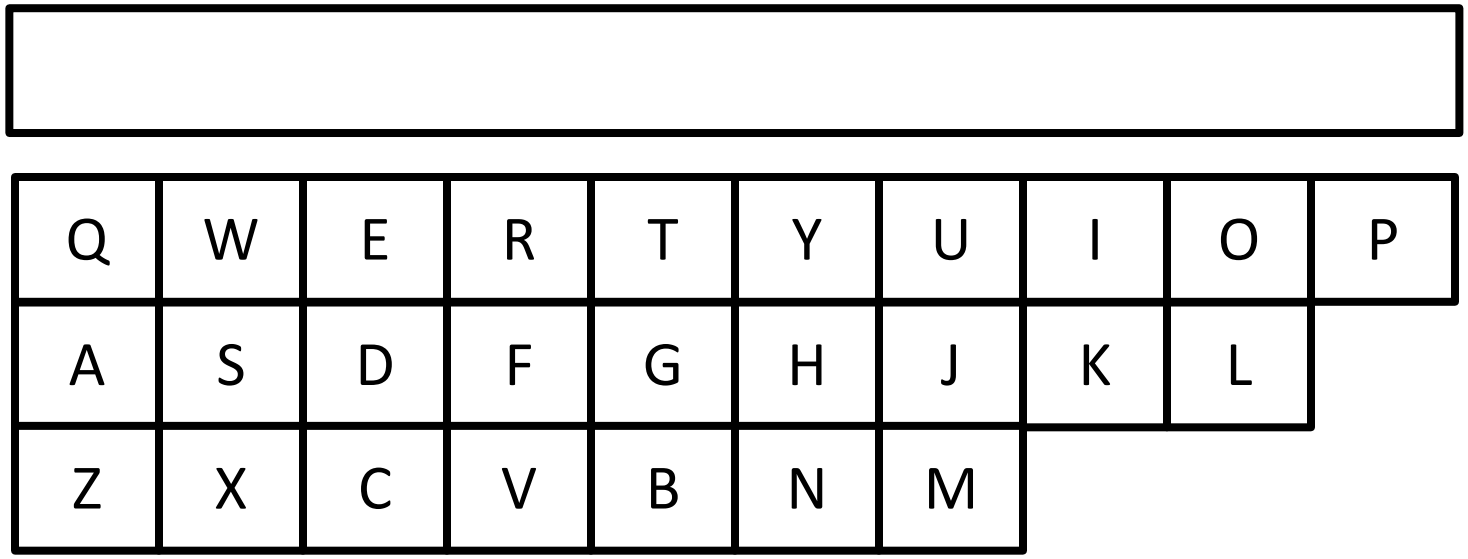
1000 ms



Record speeds achieved when writing by gaze

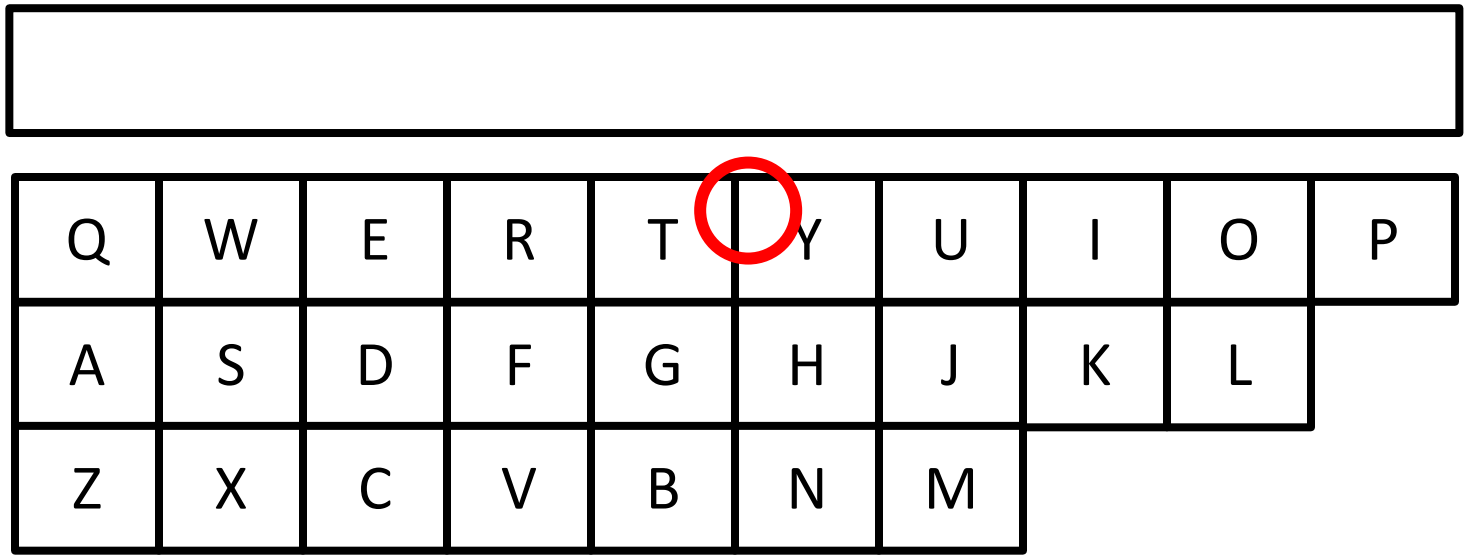
- **Eye-typing**
  - 5–10 wpm (Majaranta and Räihä 2002; Rough et al. 2014)
- **Eye-typing with adjustable-dwell**
  - 7-20 wpm (Majaranta et al. 2009; Räihä and Ovaska 2012; Rough et al. 2014)
- **Dasher**
  - 12–26 wpm (Tuisku et al. 2008; Ward and MacKay 2002; Rough et al. 2014)

Dwell-free eye-typing

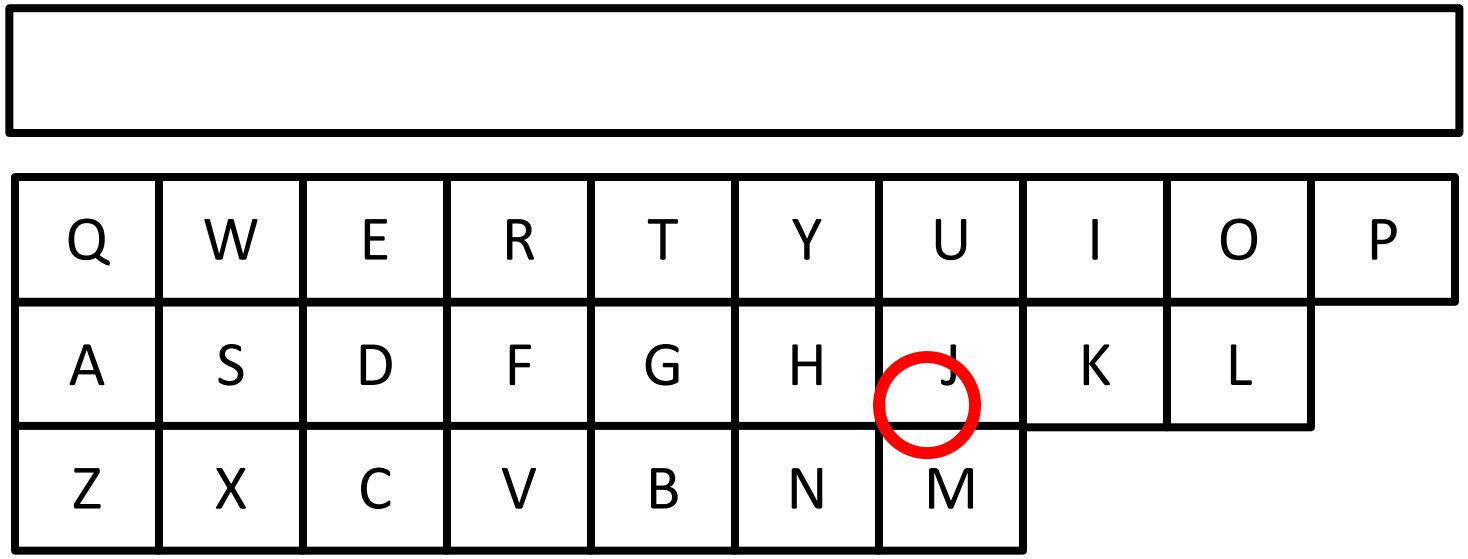


Kristensson, P.O. and Vertanen, K. 2012. The potential of dwell-free eye-typing for fast assistive gaze communication. In *Proceedings of the 7th ACM Symposium on Eye-Tracking Research & Applications (ETRA 2012)*. ACM Press: 241-244.

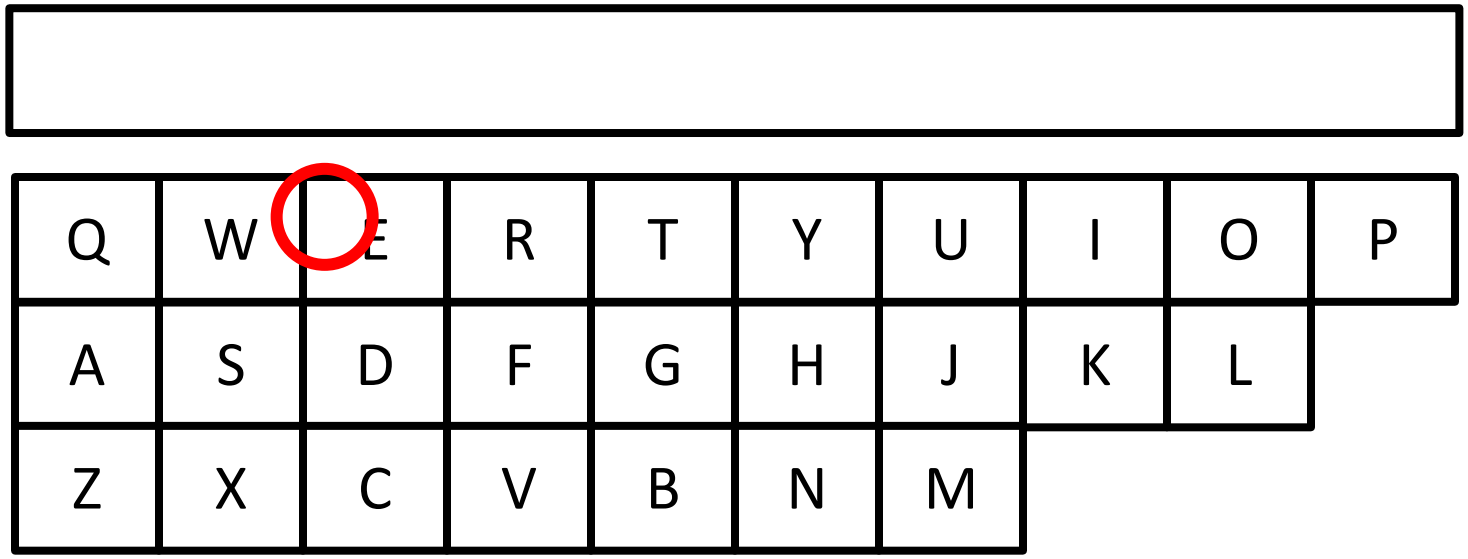
Dwell-free eye-typing



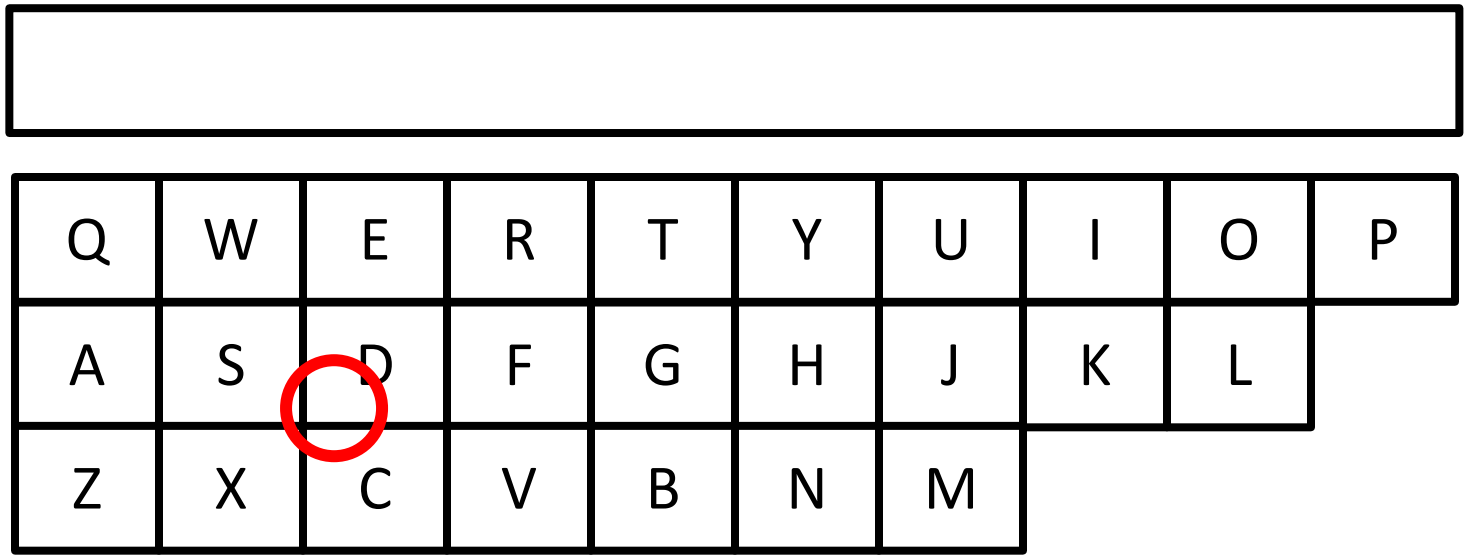
Dwell-free eye-typing



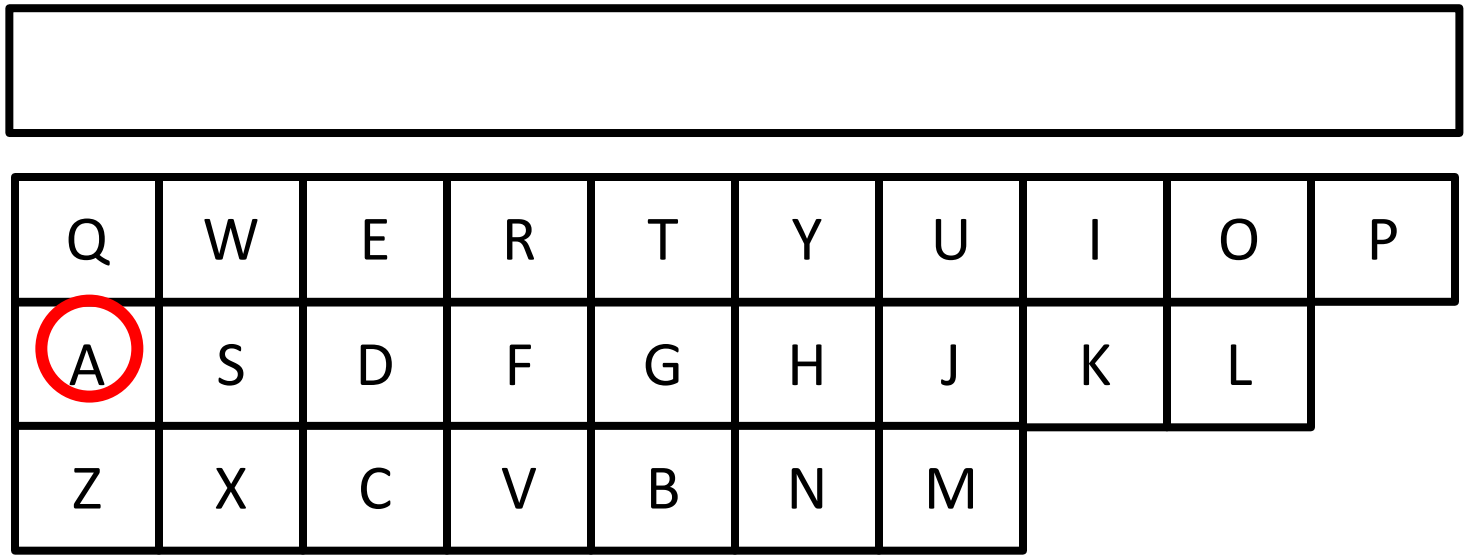
Dwell-free eye-typing



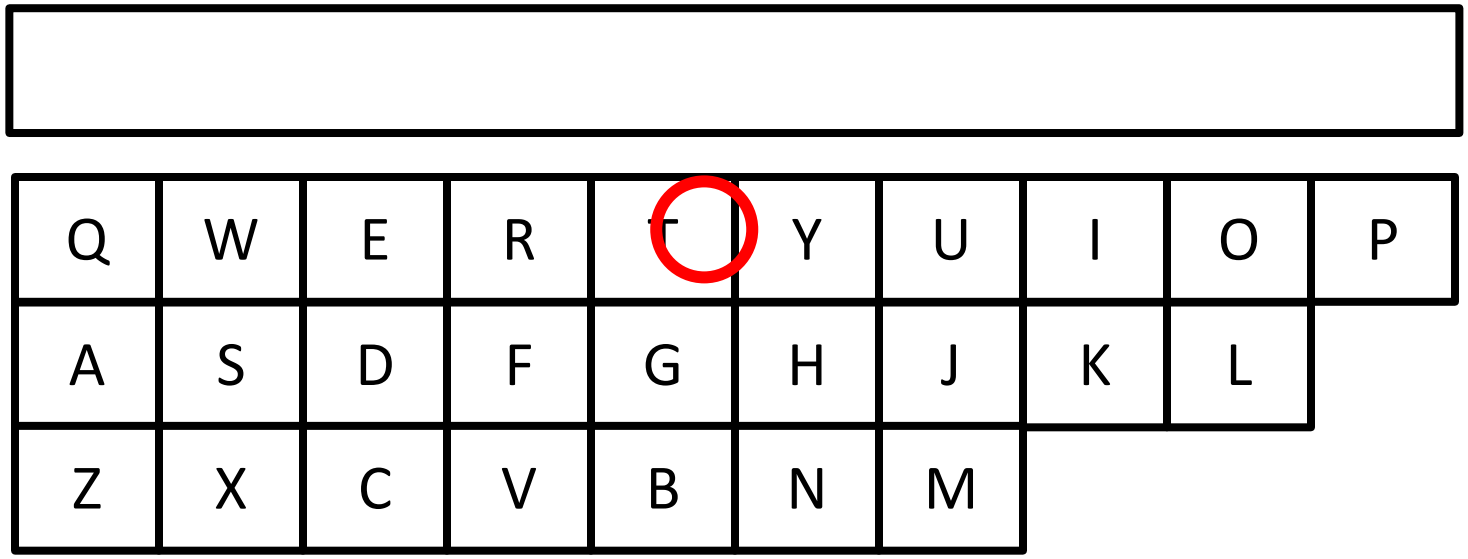
Dwell-free eye-typing



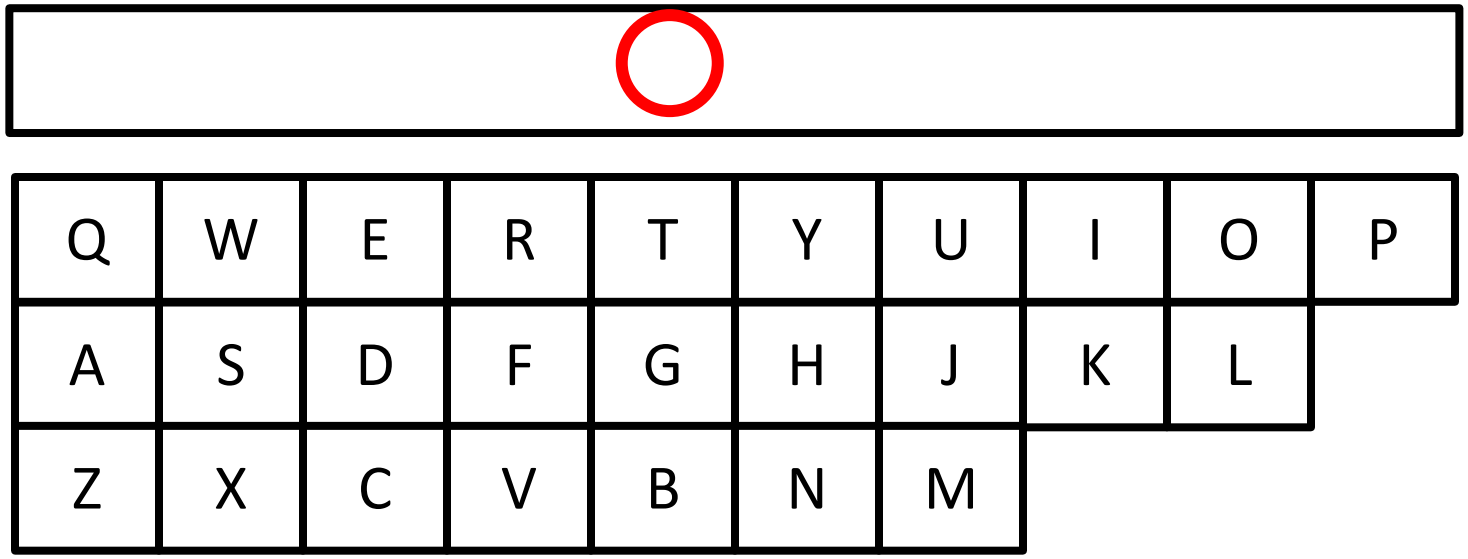
Dwell-free eye-typing



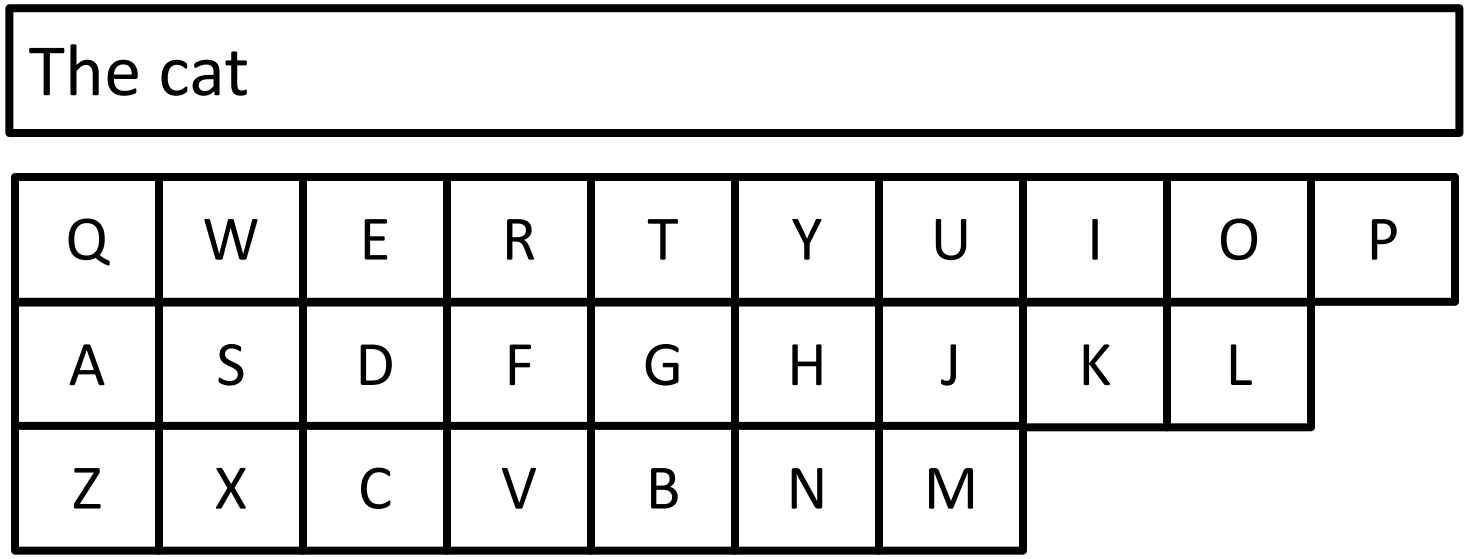
Dwell-free eye-typing



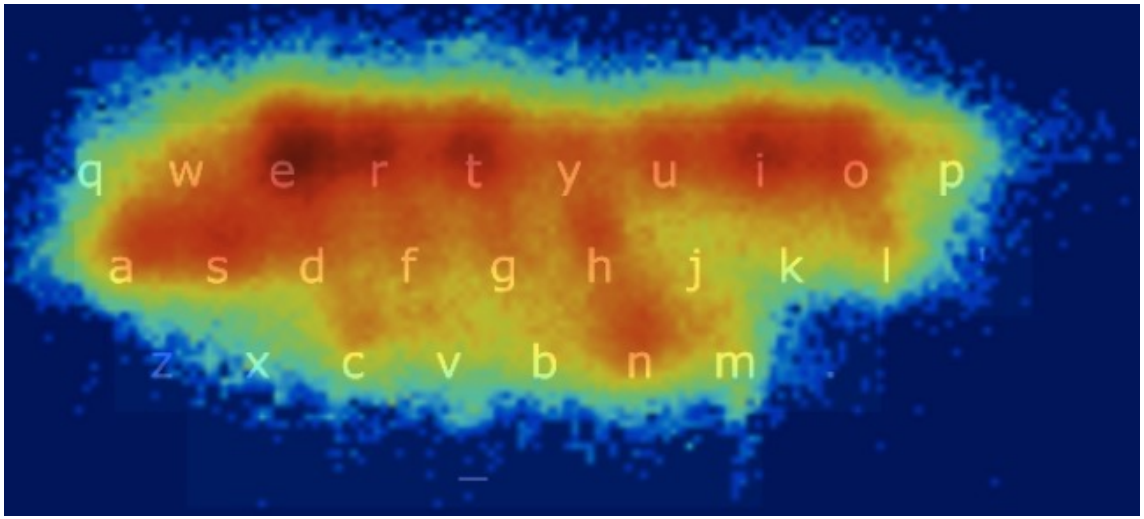
Dwell-free eye-typing



Dwell-free eye-typing

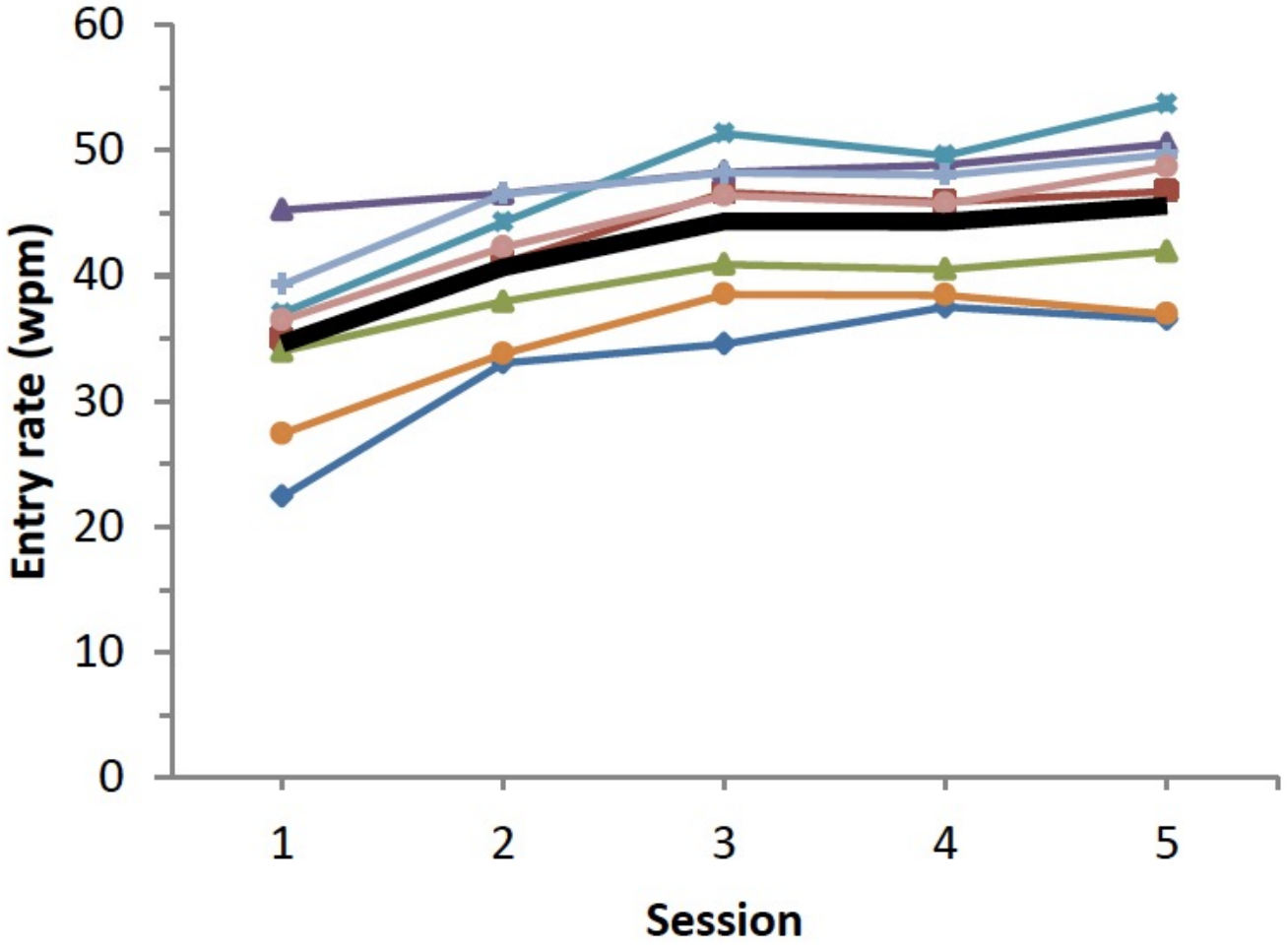


Human performance estimate of dwell-free eye-typing

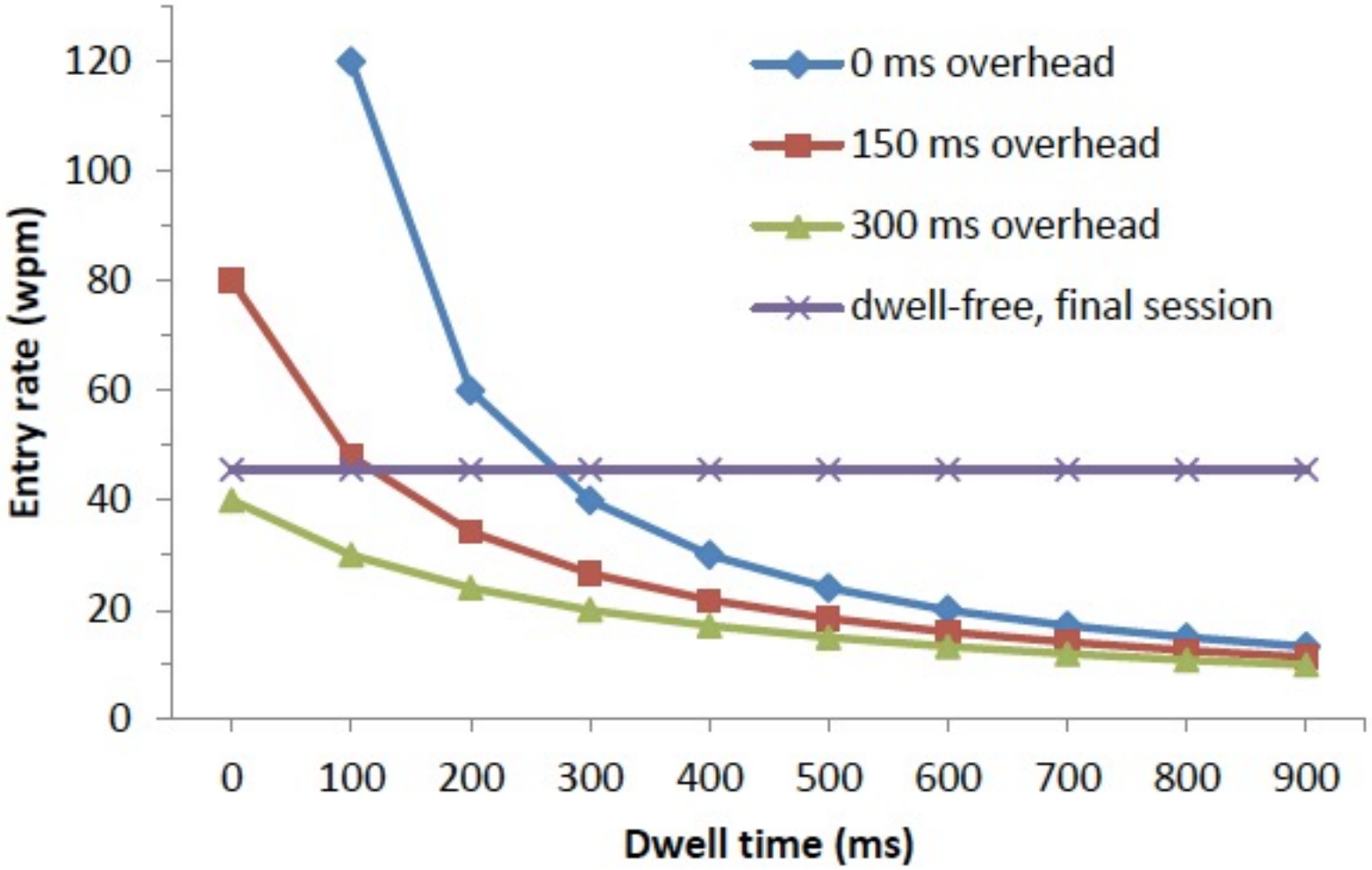


- Recorded 400 minutes of eye-trace data
- Participants entered a total of 2026 phrases
- Participants were prompted phrases and asked to copy them as quickly and as accurately as possible
- Our system knew what the user was supposed to write and verified that the user is gazing at the letter sequence corresponding to the stimulus

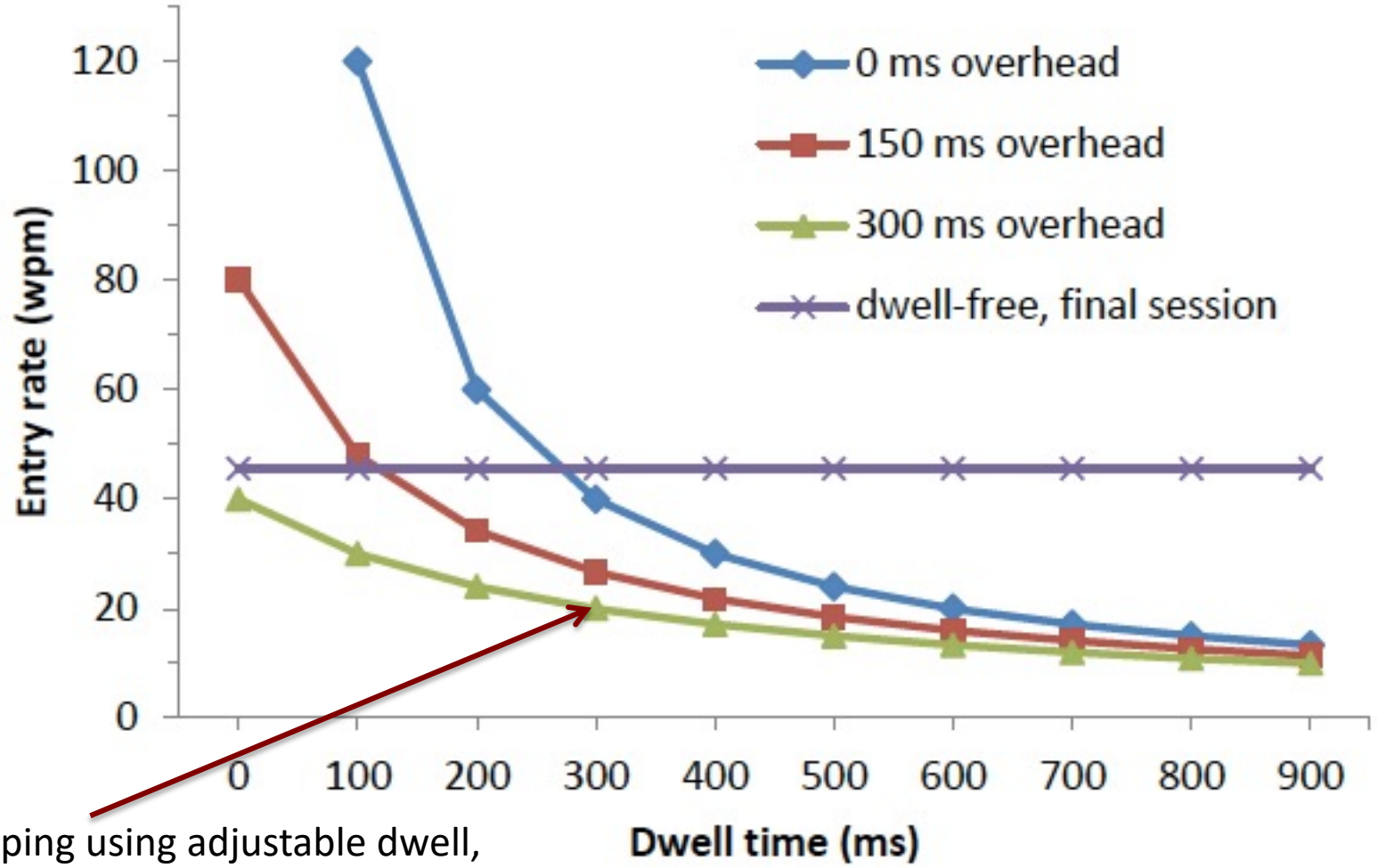
Entry rate



Human performance model

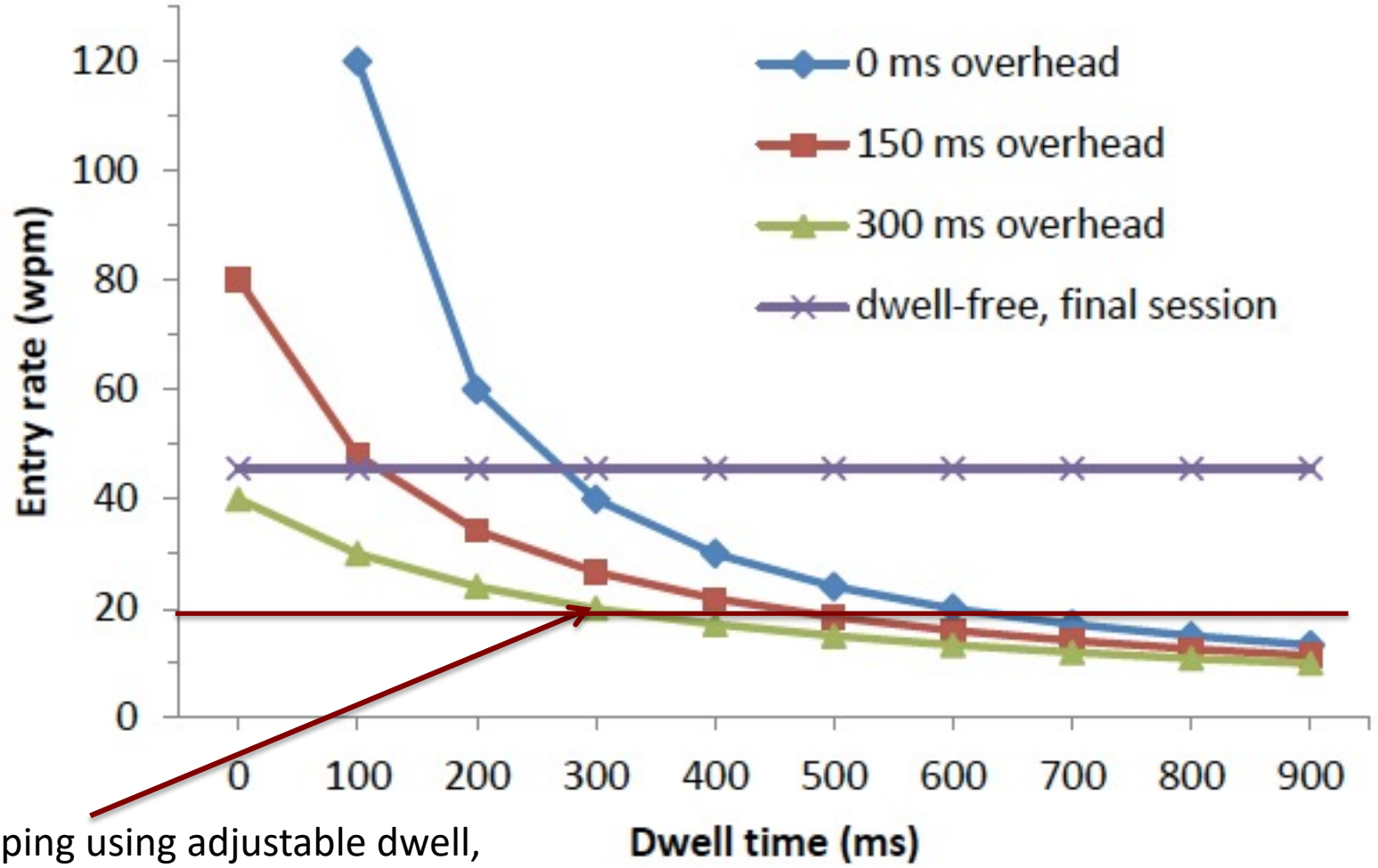


Human performance model



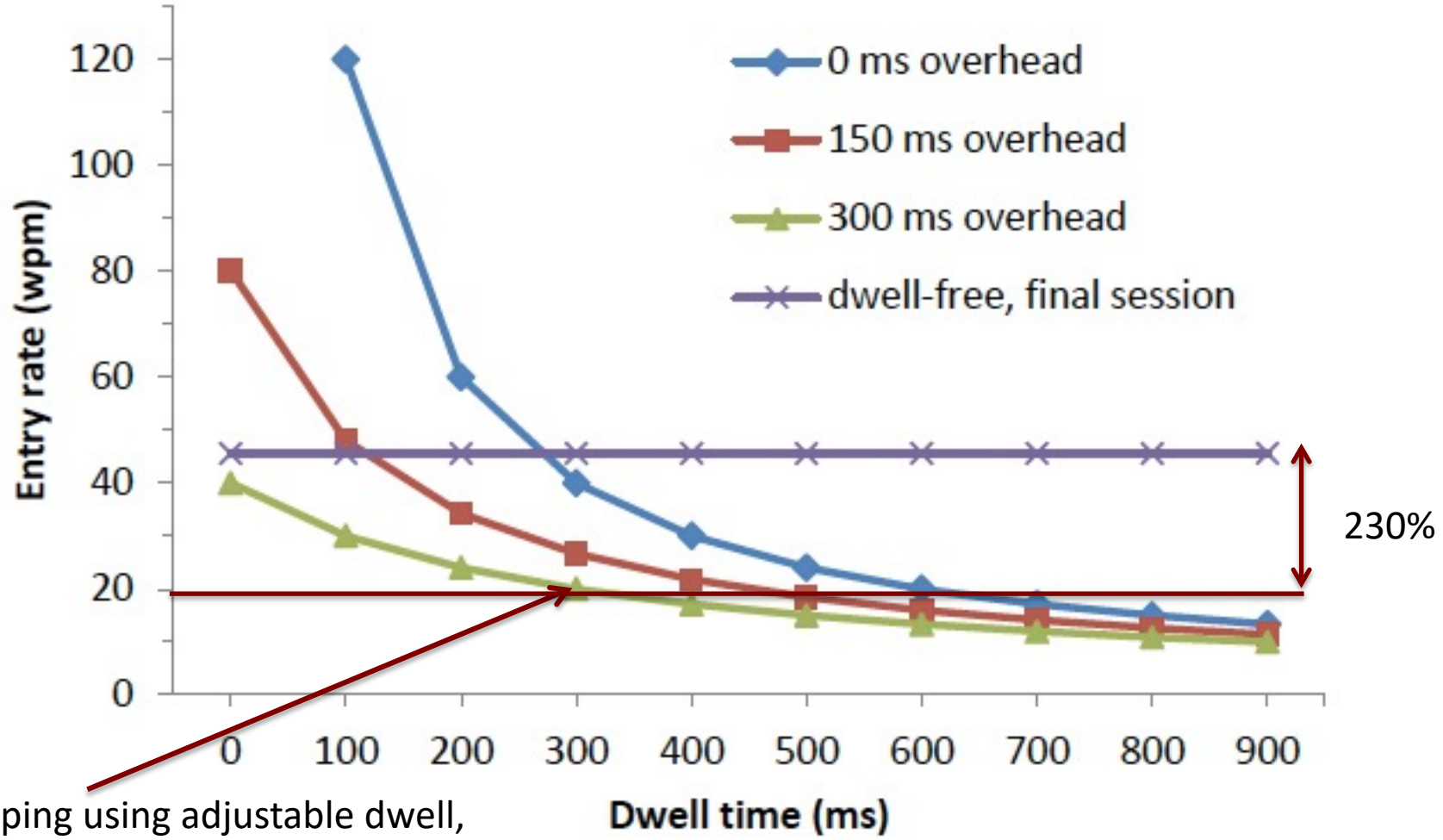
Eye-typing using adjustable dwell,
final entry rate (mean = 20 wpm)

Human performance model



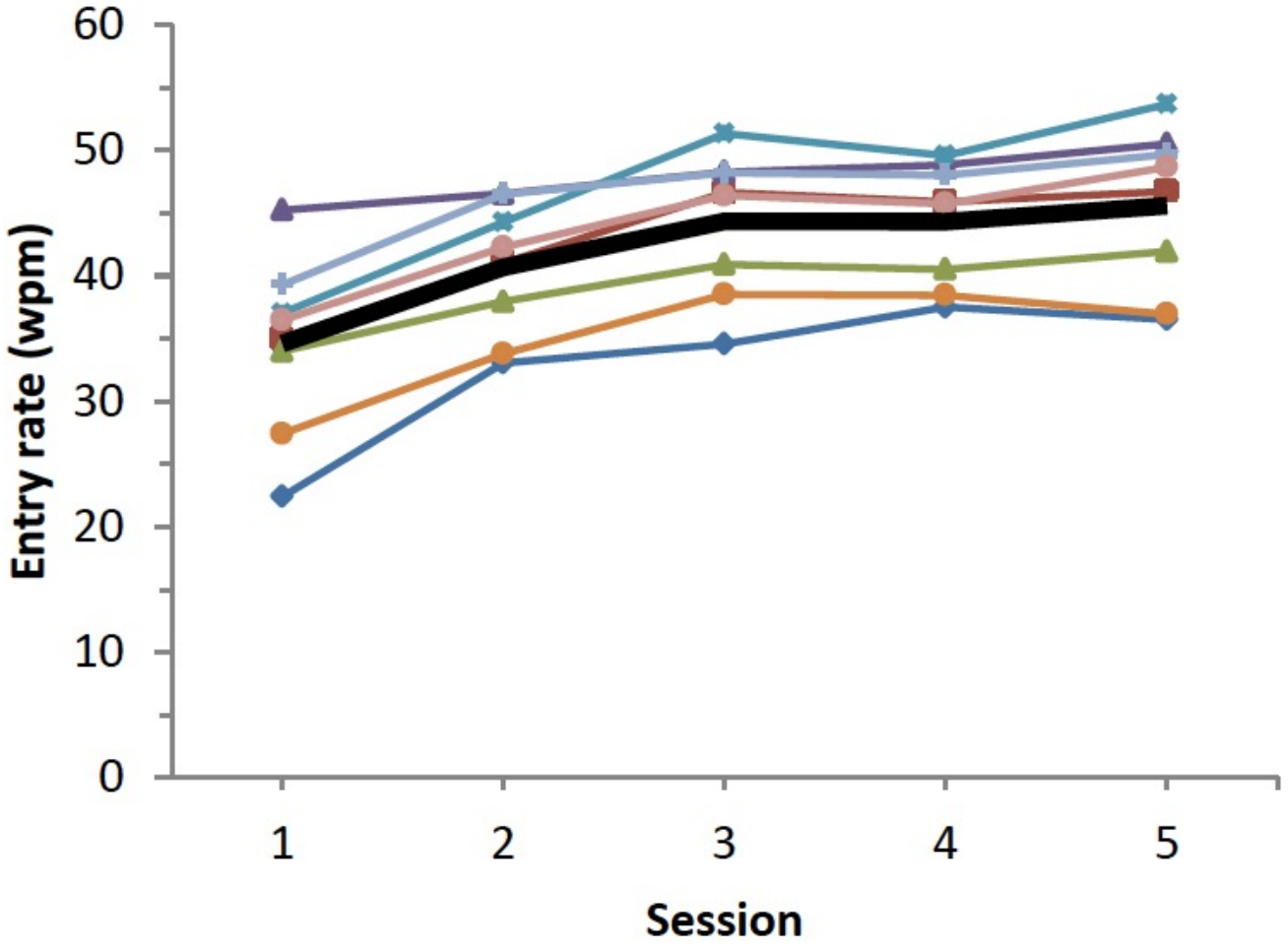
Eye-typing using adjustable dwell,
final entry rate (mean = 20 wpm)

Human performance model

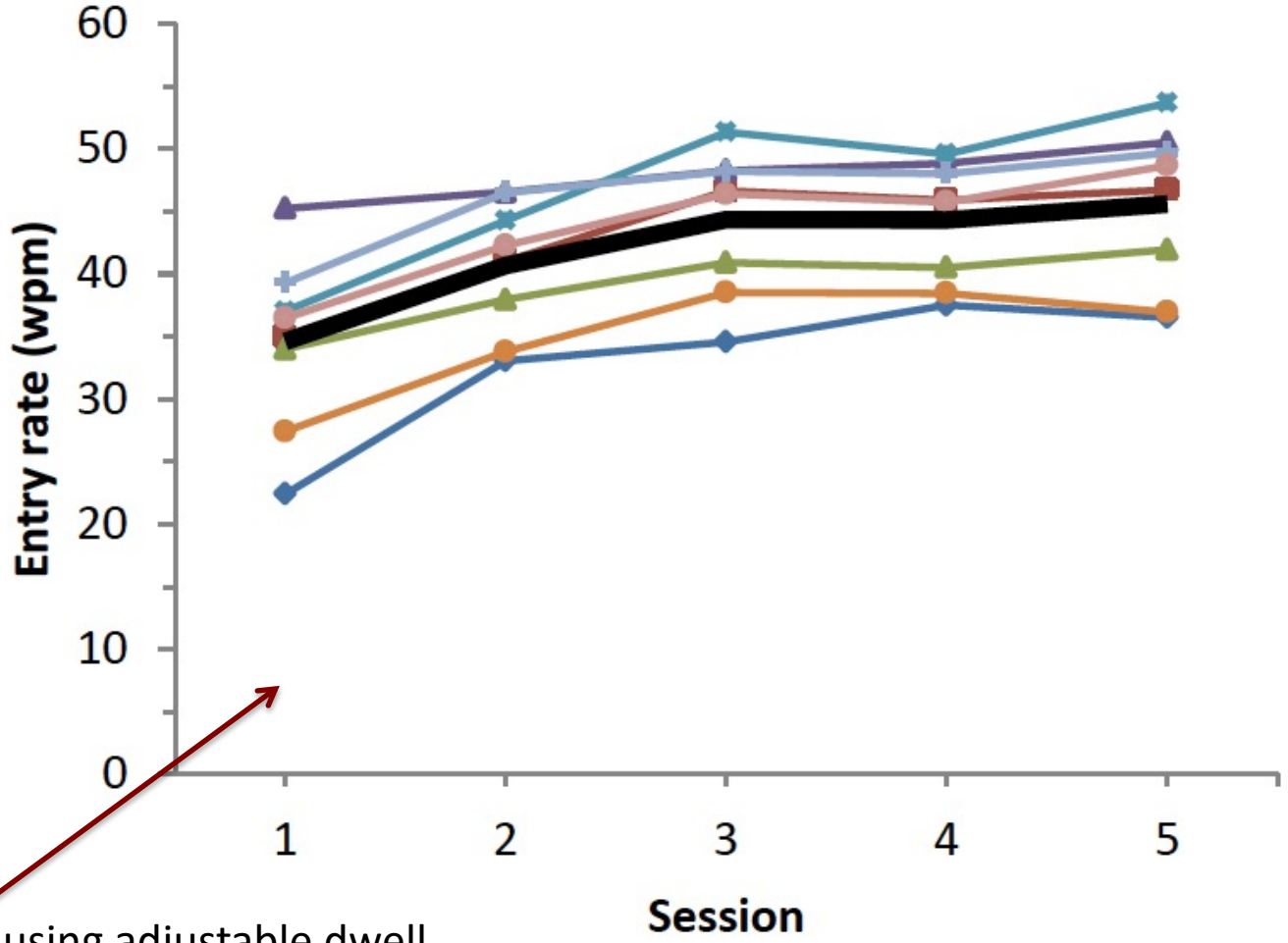


Eye-typing using adjustable dwell,
final entry rate (mean = 20 wpm)

Entry rate, first 10-15 minutes

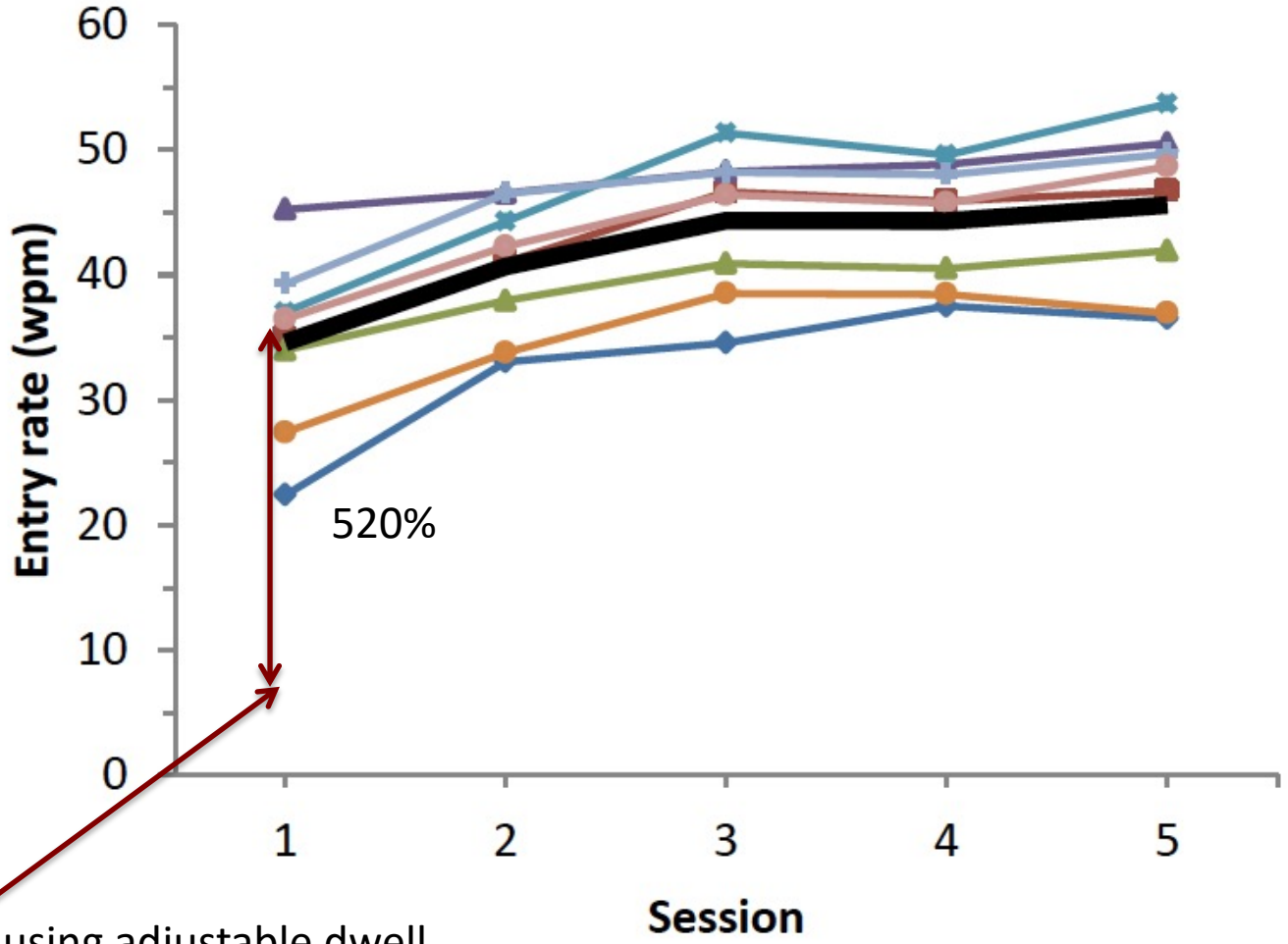


Entry rate, first 10-15 minutes



Eye-typing using adjustable dwell,
entry rate in the first session (mean = 6.9 wpm)

Entry rate, first 10-15 minutes



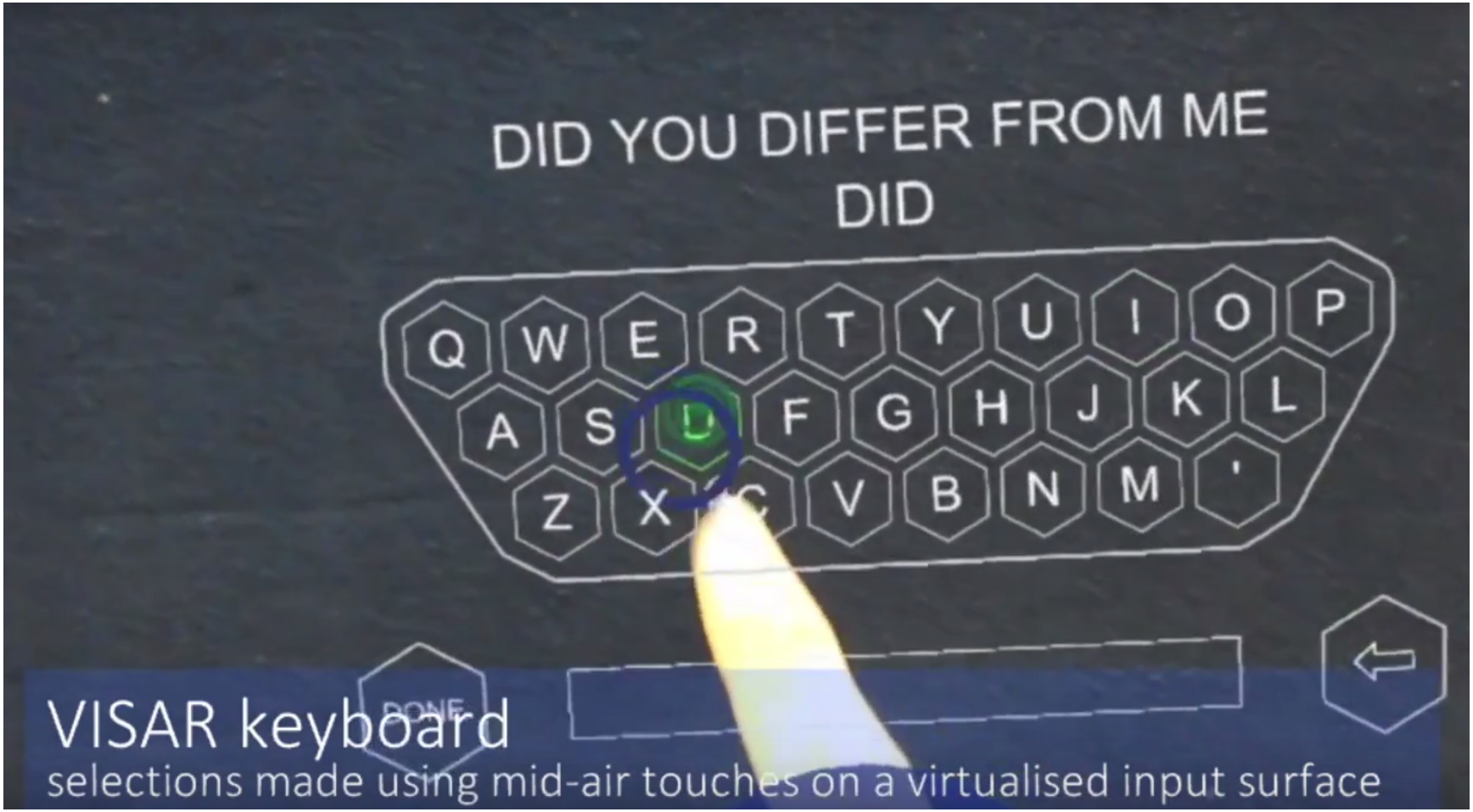
Eye-typing using adjustable dwell,
entry rate in the first session (mean = 6.9 wpm)

A step-change in gaze communication

- **Existing gaze communication solutions**
  - Limited to circa 20 wpm
- **Dwell-free eye-typing**
  - Empirically measured human performance potential: 46 wpm average

- Released as a product: Tobii-Dynavox I-Series+

Typing in thin air using depth sensor and an optical see-through head-mounted display



Dudley, J.J., Vertanen, K. and Kristensson, P.O. 2018. Fast and precise touch-based text entry for head-mounted augmented reality with variable occlusion. *ACM Transactions on Computer-Human Interaction*: in press.

Typing in thin air using depth sensor and an optical see-through head-mounted display

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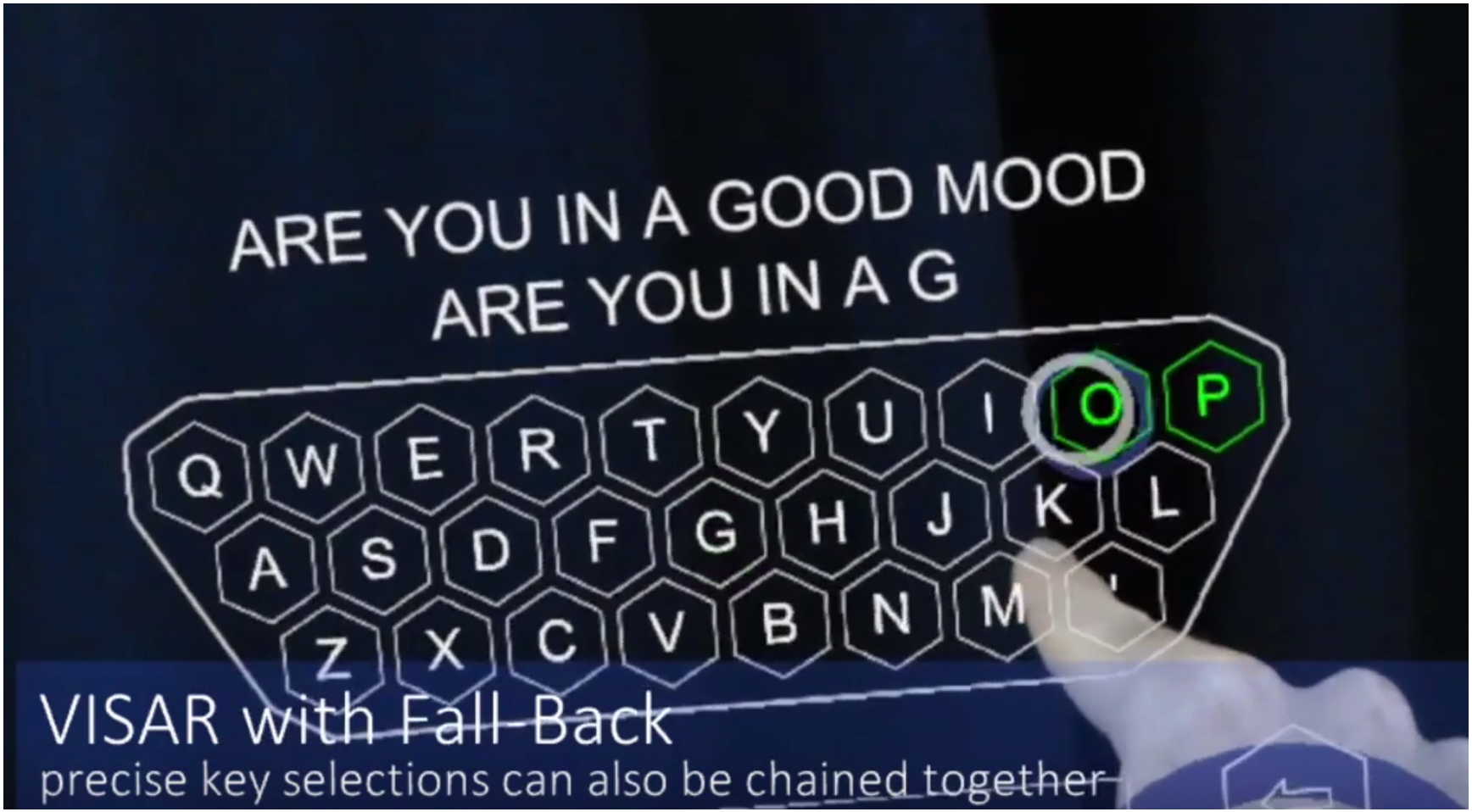

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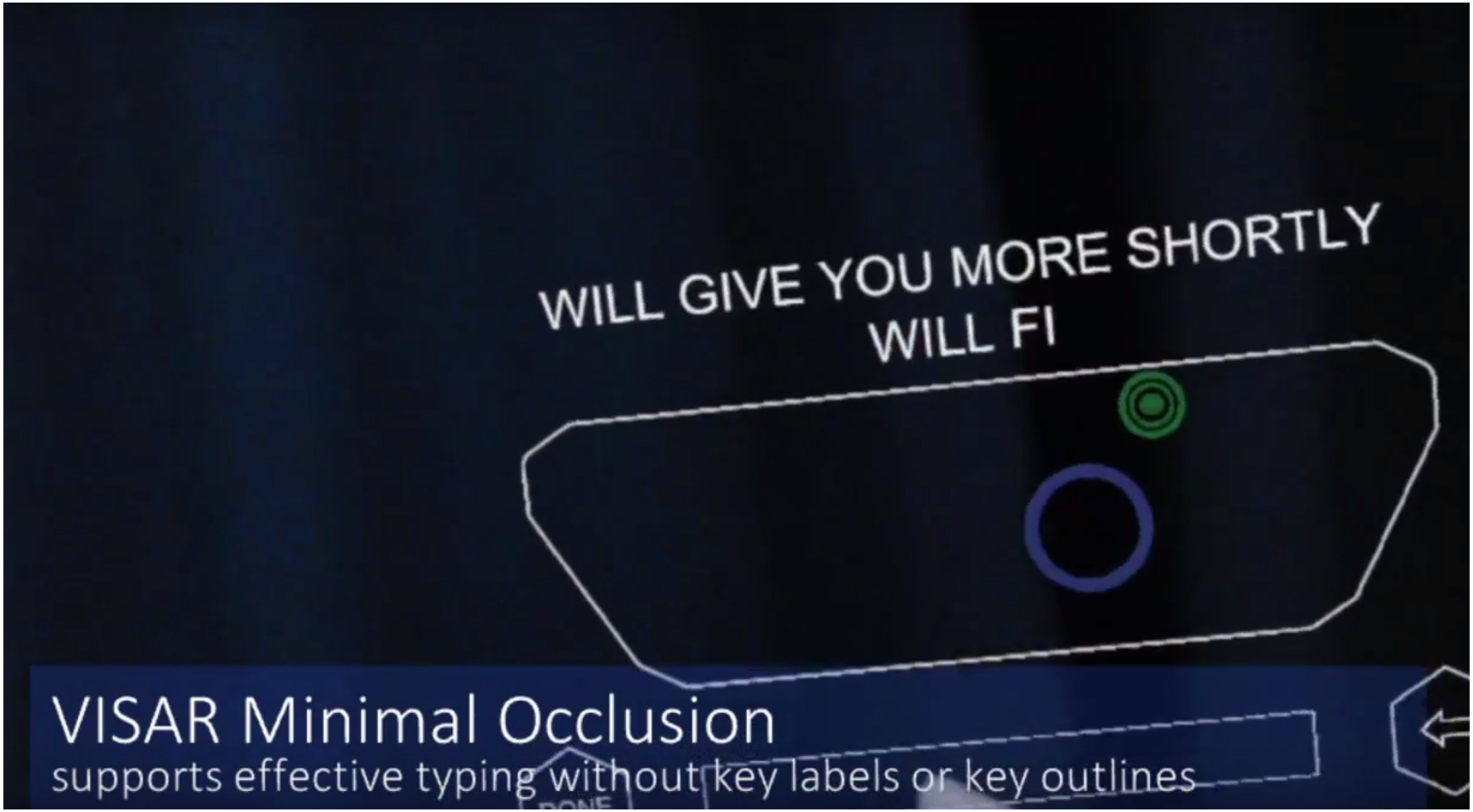

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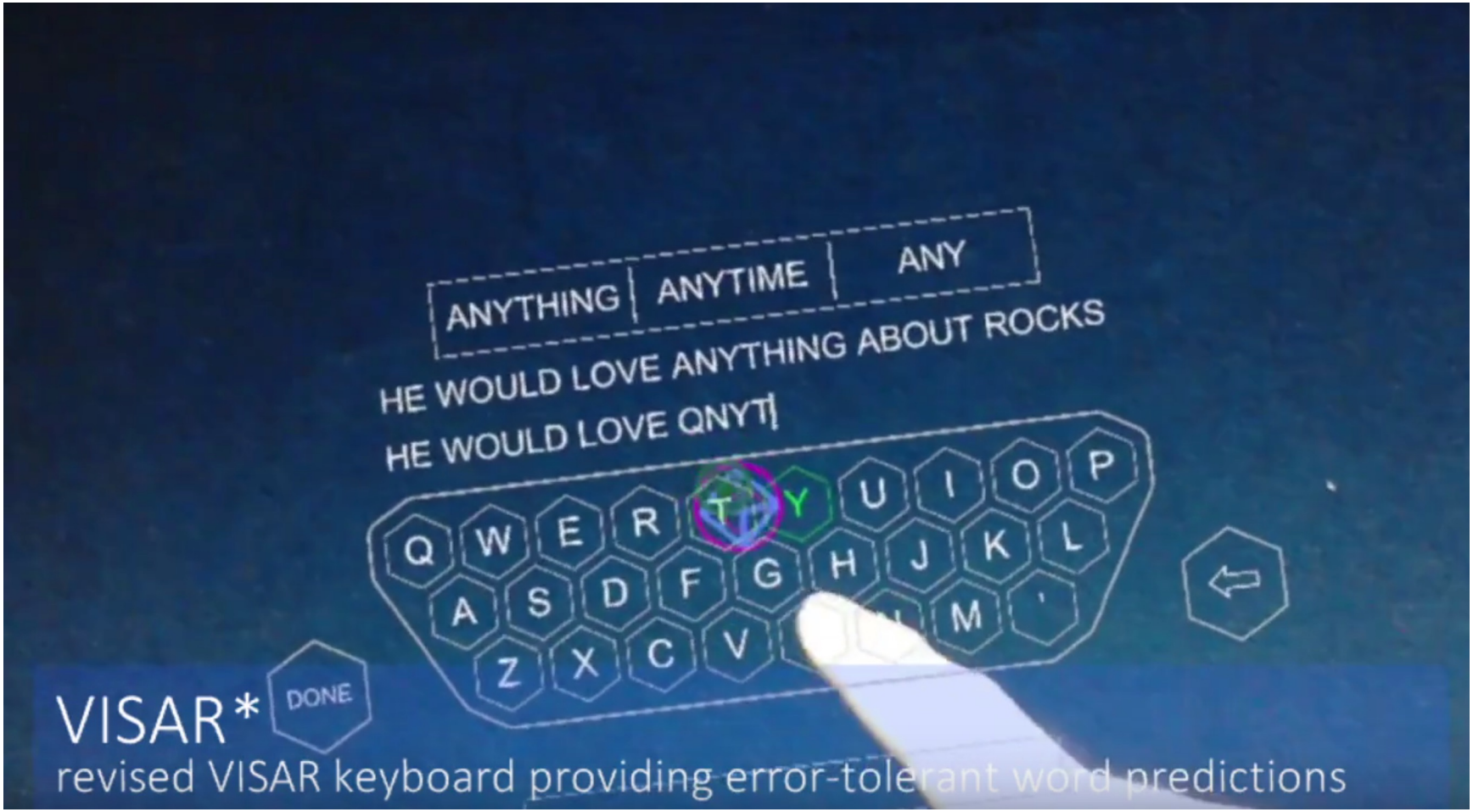

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For the next lecture

- Search the news, the research literature, the professional literature (specialist magazines) and/or just use your creativity to come up with a proposal for an intelligent interactive system
- Prepare a 1-minute presentation of your progress to the entire class
  - In your presentation (which will be **timed** and must be **very brief**) you should present:
  1. The problem domain/context and the actual problem
  2. A solution-neutral problem statement (see handout on the Moodle site on how to achieve this)
- You should ensure you **read extensively** about your problem domain and you should be aware that copying an existing intelligent interactive system for a known problem is likely to result in an **unimpressive** final report. You should also be aware of the department's **plagiarism** policy, the department treats plagiarism very, very seriously.
- However, your problem does not need to be completely original. A good problem is realistic and can be solved **with today's knowledge**
- Remember that by setting the problem you are implicitly simultaneously the client and the engineer. Therefore, ensure it will be actually feasible to design a solution.
- After the next lecture, **I will take the role of the client and I will be throughout this module probing you about your design and question how it solves *my* needs**