Human Perception

> **Human Perception:** How we gain information from our environment including senses, awareness, interpretation and understanding.

Model Human Processor (MHP)

A **cognitive model** of the user as a computer, stating they have:

Processors

Perceptual

Cognitive

Motor

Hierarchical Memory

Working Memory

Long-term Memory

Understanding how humans process information **informs design** because representations affect perceptions.

Representing Information

Information can be represented in **many ways**, making it easier or harder to complete a task or solve a problem.

- **Perception extends our working memory to our environment**, and we work with external representations of our goals. *e.g. diagrams, user interfaces*
- Users form a **mental model of a UI** based on their perception.
- Users seek information **quickly** with **little effort**.

Perception Filtering

Our perceptions are filtered by our expectations and biases.

Attention

Attention impacts which information the brain filters, there are two types:

Selective Attention	*Divided Attention*
• Concentrating on **one task**. • Allows us to prioritise competing stimuli. • Limits our ability to keep track of all events.	• **Splitting attention** between multiple stimuli. • Switching between tasks.

Attention is **directed** by two types of cues:

Exogenous / Bottom-up	***Endogenous / Top-Down***
External stimuli which draw attention. *e.g. noises & visual features that pop out.*	Driven by goals, so we focus on task-relevant stimuli.

Blindness

Blindness causes people to miss information, there are two types:

Inattentional Blindness	***Change Blindness***
Missing something because **our attention is directed elsewhere**. Not consciously ignored but pre-consciously filtered! *e.g. users focus on the screen section they're engaging with.*	Missing a difference between a previous and current state. *i.e. leads to a tendency to overlook UI changes.*

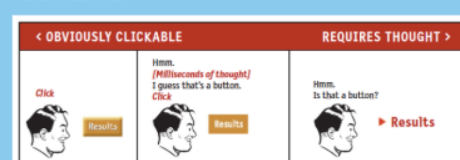
Perception Bias

Our perceptions are biased by our expectations, formed by past experience, present context and goals. There are three types:

Experience Bias: Buttons are often clicked without looking carefully, based on experience. So, subtle changes can cause problems!

Goal Bias: Selective attention to goal-relevant information, resulting in inattentional blindness.

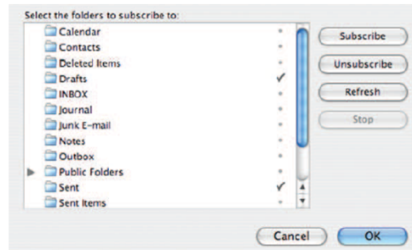
Context Bias: Objects are be perceived differently based on the context. For example, visual context:



Visual Structure

Representations matter because we have a **tendency to perceive structure**, like shapes, figures and objects, which helps us to scan and **learn information efficiently**. Two representations can display the same information, but require different cognitive power.

The Laws of Gestalt



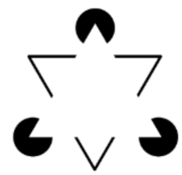
Describe how human vision is optimised to see structure.

Proximity, Similarity & Common Fate

Close, similar and moved together objects **connote groups**.

Continuity, Closure & Symmetry

Vision is biased to perceive continuous, close and symmetric forms, which helps to resolve ambiguity.



- **Continuity:** We add missing data to help us perceive whole objects.
- **Closure:** Perceiving the whole event though parts are occluded.
- **Symmetry:** Our vision chooses the simplest interpretation, with highest symmetry.

Figure & Ground

Our minds **separate the visual field** into the **figure** (foreground) and **ground** (background), helping with UI design. *e.g. popups and dialog boxes.*

- **Foreground:** Elements for primary attention.
- **Background:** Everything else.

Visual Hierarchy

Breaking information into **distinct**, **labelled** and **hierarchically organised** sections helps people to **focus on relevant information**. In UI design, a hierarchy of panels and menus achieves this.

Minimise Reading

Humans are wired for spoken language, rather than written. **Feature-driven reading (bottom-up) is most effective**. In UI design, this means:

- Minimising the need for reading.
- Good typefaces & spacing.
- Familiar vocab & context.
- Format text in visual hierarchies.

Attentive Processing & Preattentive Features

Attentive processing describes how preattentive cues guide eye movements to focus foveal vision for detailed processing.

Types of Vision

Our two types of vision help us to **process information when there's too much**!

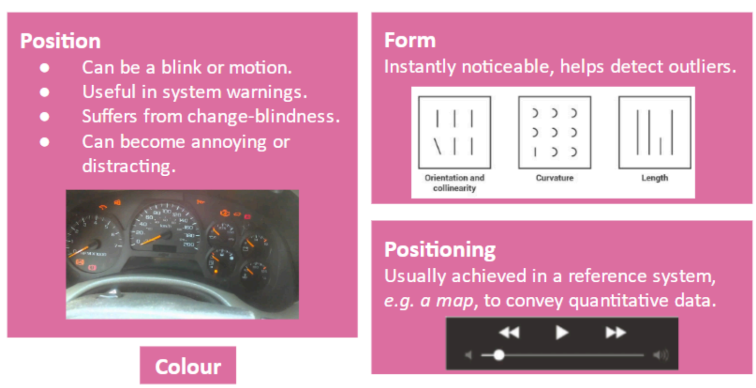
Foveal Vision	***Peripheral Vision***
Concentrating visual processing in a **small area to extract details**. ● Covers 1% of the visual field but collects 50% of the data. ● Eyes move to align with interest. ● Responsible for active sight functions. *e.g. reading, driving, etc.* ● High resolution.	**Processes spatial information outside of the foveal vision** area. ● Parallel sensing, but at low resolution. ● Looks for low-resolution **preattentive** cues to guide our eye movements!

Preattentive Features

They pop-out during parallel sensing and can be processed faster with less effort. For example:

1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

Certain visual properties achieve this because they're detected by the **low-level visual system**; in the visual cortex/sensor memory, without cognitive effort (looking). There are four types:



UI Design Implications

Important information should be placed where the user's attention is and low-resolution cues should guide them to it. Pre-attentive features should be used to provide info without eye movement.

Data Visualisation

Preattentive features can help encode different data types:

- Nominal (Categorical)
- Ordinal (Categorical w/ order)
- Quantitative data.

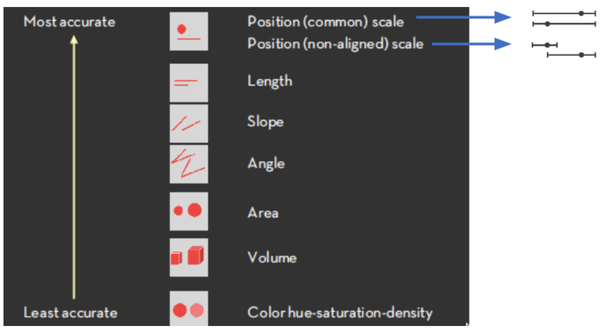
by identifying it, highlighting differences or comparing it.

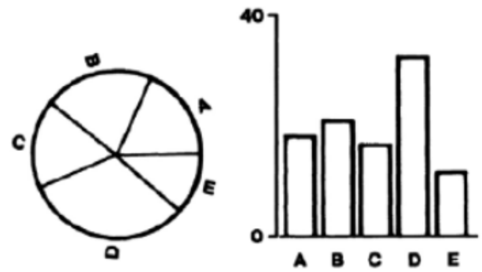
Graphical Perception

The **ability of viewers to interpret visual encodings of data**, hence decoding graphical information. There are several types of **visual encodings**:

- Colour.
- Form: Length, Size, Angle, Texture.
- Position.

It can be difficult to estimate the area or volume of shapes (the **relative magnitude**). However, it's easier to interpret the length and position of bars.

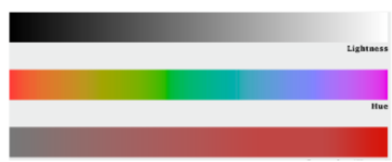




Basic Colour Theory

Colours are made up of:

- Lightness (black to white).
- Hue (red, orange, yellow, green, blue, indigo, violet).
- Saturation (dull to brilliant).



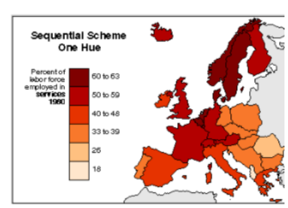
Categorical Colour Encoding

Human vision is **optimised for edge contrast**, not brightness. So, there are limitations to data representations using recognisable colours.

Scale Colour Encoding

Colour is **categorised** and **unordered**, so can encode **nominal variables**.
Brightness is **ordered**, so can encode **ordinal data**.

Don't use a rainbow because the colours have **no inherent meaning.**



Colour Vision Deficiency (CVD)

The **inability to distinguish certain shades of colour**. Confusion can be avoided by also using shape & brightness.

Mental Models

Users must build a **mental model** of how a UI works to use it. **Gulfs in understanding** between users and computers are **bridged by interface design**.

Gulf of Execution
Learning the actions needed to achieve certain goals.

Affordances

Actions made possible by UI elements. Help UIs bridge the gulf of execution; users learn how inputs & affordances map to goals.

- UI elements that convey, support or enable actions are called affordances.

Types

Cognitive: Connote possible actions. *E.g. button labels indicating actions.*

Physical: A conduit for physical interaction, with no guarantee of something happening. *E.g. scroll wheel.*

Functional: Responds to input to affect an outcome. *E.g. clicking the mouse button (physical) on the icon (cognitive) adds the item to your cart (functional).*

Sensory: Help users sense cognitive and physical affordances. *E.g. highlighting actions*

Broken: Connote multiple affordances.

Gulf of Evaluation
Not knowing the result of actions. UIs should give feedback!

Intuitive UIs

Affordances and feedback needs to be learned, so UIs need to be **self-explanatory**:

- Use affordances which can be learned quickly.
- Use feedback to teach about functional affordances.

Mental models are rarely perfect, so UIs must anticipate errors!

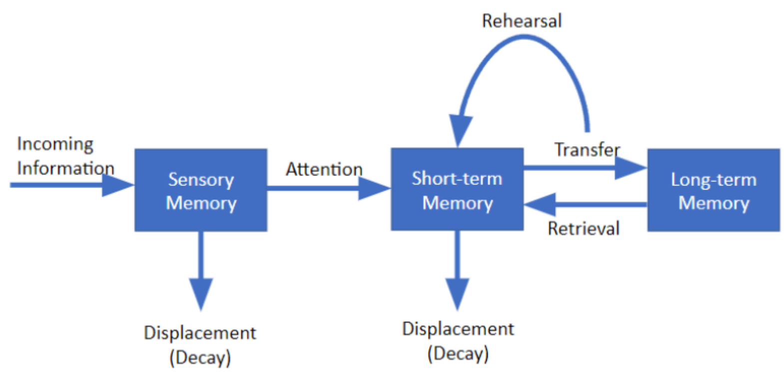
Memory & Attention

Memory is characterised by **storage capacity (U)** and **decay time (D)**. It has a few types of **hierarchical memory**:

- **Sensory:** Like an input buffer.
- **Short-term (Working)**: Keeps a few items for a short time.
- **Long-term:** Unbounded.

The Multi-Store Model

Memories are **formed when the brain responds to perceptions with neural activation**. Retrieval strengthens memories and is caused by similar perceptions (recognition) or other activity that triggers it (recall).



Short-Term/Working Memory

Anticipate what users need in working memory and make it visible!

Short-term memory has a **limited capacity** and information in it depends where **attention is focussed**. It's **highly volatile** because focussed attention or distractions lead to information loss.

Long-Term Memory

Stored memory containing **nearly everything we've experienced**, but we can't retrieve it all.

- **Imperfect:** Detail varies.
- **Impressionist:** Weighted by emotion.
- **Retroactively Alterable:** Memories can be rewritten.

Memory Retrieval

Activating a memory to be used in working memory.

Recognition

Triggered by similar perceptions.

- Perception and long-term memory working together.
- Used to assess situations quickly.

Recall

Reactivates stored memory without perceptual input.

- **Harder**.
- Like memory lookup.

Support recognition where possible. *I.e. icons, thumbnails*

Human Behaviour Patterns

Use the acronym PEGSUFF!

There are seven key patterns which inform UI design:

1. Goal, Execute & Evaluate

People think in cyclic patterns, which help us to break tasks down into unit tasks.

1. Form a goal.
2. Choose and execute an action.
3. Evaluate the result.

2. Unit Tasks

Humans can only accomplish **small tasks with unbroken attention.** All information must be directly accessible. So, break down large tasks.

3. Focus on Goals not Tools

Humans focus on a task's **goal and information**, rather than the tools to complete it. So, design tools which need little attention.

4. External Aids to Keep Track

Humans use **external representations to reduce memory load**:

- **Reading:** Bookmarks to track page.
- **Checklists:** Track short-term goals.

The UI should provide these.

5. Scent of Information

Humans **follow a scent of information,** and only pay attention to promising leads meaning users won't check all options and make choices on the goals and predictions.

6. Prefer Familiar Paths

Users **take a familiar path** when possible rather than exploring new ones because it's automatic and efficient. So, UIs should guide users to the best routes.

7. Forgetting to Clean Up

Brains **divert focus from unimportant tasks** to avoid wasted power. Once a goal is achieved, its working memory is lost, so people forget to clean up. Good design prevents this.

Nielsen's 10 Usability Heuristics

Use the acronym **VEMCHUFFER!**

1. Visibility of System Status

Gulf of execution & limited attention mean the system should provide status feedback and where the user is in an interaction flow, including:

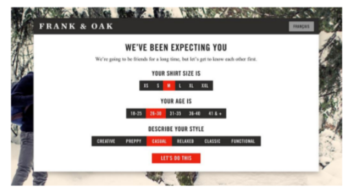
- **Time:** Feedback depends on response time. *e.g. loading bar*
- **Space:** What will change?
- **Actions:** Options.
- **Task:** Feedback depends on goals: multi-step, next step or completion.

2. Familiarity

Use familiar language, metaphors, categories and choices to explain the unfamiliar, as they're easy-to-learn affordances.

3. User Control & Freedom

Freedom should be appropriate for the user & task, like the ability to exit from mistaken choices, undo and redo. Don't force users down a fixed path.



Leading with defaults but freedom to make other choices.

4. Consistency

Consistent layout, names & choices, as they're easy-to-learn affordances.

5. Error Prevention

Avoid incorrect mental models by preventing data loss, clutter, bad inputs & confusing flow. There are two types of error:

Slips	***Mistakes***
User has the **right mental model** but slips up accidentally.	User has an **incorrect mental mode**l, and does what they intend to.

6. Recognition Over Recall

Recognition is easy, recall is hard. So, information needed should be visible or easily retrievable. *e.g. avoid using codes and instructions.*

7. Flexibility & Efficiency

Advanced tasks for expert users should be fluid and efficient with shortcuts & recommendations. Derives from the need to explore without risk.

8. Minimalism

Help users focus attention by keeping UIs simple & easily visually accessible by only implementing necessary functionality.

9. Error Recovery

A good UI should help users recognise, diagnose and recover from errors to clarify incorrect mental models:

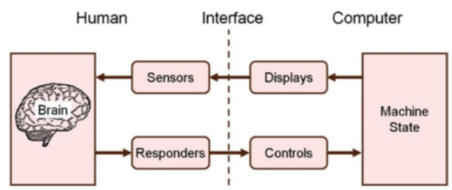
- Making the problem clear.
- Providing a solution.
- Showing a path forward.
- Proposing an alternative.

10. Help

Provide integrated help with explorable examples, steps for interactions and pointing things out.

Actions & Devices

The **human factors view** illustrates the interaction between humans and computers.



Eyes are an active sensor (foveal and peripheral vision) and motor control!

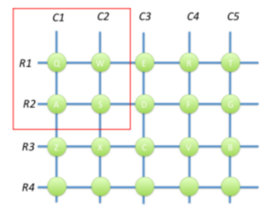
Actions

Most HCI is fingers to screen:

- **Discrete:** Keyboard typing, touchscreen taps.
- **Continuous:** Dragging & drawing.
- **Gestures:** Flicking & pinching.

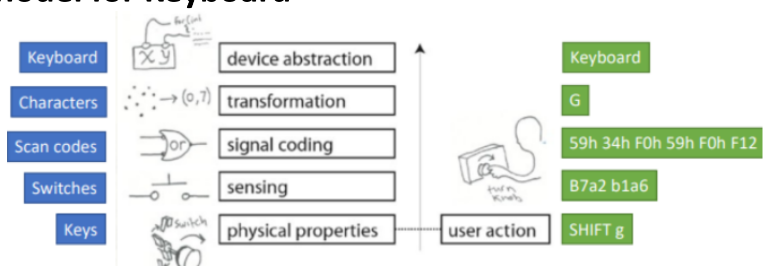
Other inputs include hands, feet, voice, etc.

Input Devices



Translate actions into inputs. For example, keyboard encoders contain a switch and store buttons as rows & columns. When pressed, a **scan code** is produced and associated with a character **depending on what's assigned**.

Layered Input Model for Keyboard



Controls

Semantic matching uses pre-defined semantics to map inputs to controls.

Spatial matching maps inputs to controls based on position. *E.g. mouse selection*

Hard Controls: Keyboards, mouse, etc.

Soft Controls: UI elements that handle input.

The distinction can be a bit blurry. Each **soft control is manipulated by a hard control**.

Explicit Control: Deliberate action.

Implicit Control: Other actions, removing cognitive effort.

Example: Virtual Keyboards

- Lacks tactile feedback.
- Less efficient: limited WPM.
- Enables gestural input.
- More languages.

Display-Control Relationships

Spatial Mapping

Maps from the control space to the display space. The more elements, the higher tier relationship. *e.g. a three-tier relationship:*

CD Gain

A **ratio of display movement to control movement,** often non-linear and with a trade-off between speed and accuracy.

$$CDgain = \frac{V_{pointer}}{V_{device}}$$

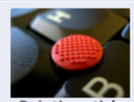
Latency

The **delay between input and response**, affected by sampling rate and framerate. The response must be under 0.1s for human brains to perceive a cause-effect relationship.

Properties Sensed

- **Position:** Absolute coordinate. *e.g. touchscreen.*
- **Displacement:** Movement relative to last sample. *e.g. mouse.*
- **Force:** Force applied. *e.g. isometric joystick.*

Properties Controlled

Sensing	Property sensed	Transfer function	Order of Control	Example
Displacement	Isotonic – no resistance	Position control	Zero-order: position	
Force	Isometric – no motion	Rate control	First-order: velocity (rate control)	 Pointing stick: harder to learn, but avoids clutching.

Modes

User actions can have **different effects depending on the system's mode**, useful where there are **more functions than controls**. *e.g. capslock*

Errors

Users often forget the system's mode. For example:

- Not resetting to the default after goal accomplishment.
- Not noticing the system has returned to default.

Avoid modes and provide state information!

Modelling Input Performance

Allows assessment of design effectiveness. Different tasks have different ideal metrics and timescales. The **time scale of human action** can be used to assess this:

Time-on-task is most common.

Scale (sec)	Time Units	System	World (theory)	
10^7	Months		SOCIAL BAND	Exploring, Navigating, Decision-making etc.
10^6	Weeks			
10^5	Days			
10^4	Hours	Task	RATIONAL BAND	High-level tasks
10^3	10 min	Task		
10^2	Minutes	Task		
10^1	10 sec	Unit task	COGNITIVE BAND	Low-level tasks
10^0	1 sec	Operations		
10^{-1}	100 ms	Deliberate act		
10^{-2}	10 ms	Neural circuit	BIOLOGICAL BAND	Input, Feedback, Interaction techniques.
10^{-3}	1 ms	Neuron		
10^{-4}	100 µs	Organelle		

Human Time Requirements

0.1 seconds limit to feel like **instantaneous reactions**.

1 second limit for user's thought flow to be **uninterrupted**.

10 second limit for **keeping user attention**.

Keystroke Level Model (KLM)

Predicts physical reaction times for a sequence of inputs, **assuming users are experts of the UI so always know where to click**. First, describe the task with a sequence of inputs and sum it. Mental preparation before typing, retrieving a memory, verifying an action, etc.

Code	Operation		Time
K	Key press and release (keyboard)	Best Typist (135 wpm)	0.08 seconds
		Good Typist (90 wpm)	0.12 seconds
		Poor Typist (40 wpm)	0.28 seconds
		Average Skilled Typist (55 wpm)	0.20 seconds
		Average Non-secretary Typist (40 wpm)	0.28 seconds
		Typing Random Letters	0.50 seconds
		Typing Complex Codes	0.75 seconds
		Worst Typist (unfamiliar with keyboard)	1.20 seconds
P	Point the mouse to an object on screen		1.10 seconds
B	Button press or release (mouse)		0.10 seconds
H	Hand from keyboard to mouse or vice versa		0.40 seconds
M	Mental preparation		1.20 seconds

Example

Adding "brown" to "The quick fox jumps over the lazy dog.":

1. Move hand to mouse (H).
2. Position mouse after "quick" and click (P, B, B).
3. Move hand to keyboard (H).
4. Formulate word to insert (M).
5. Type "brown" (K*6).
6. Reposition cursor to sentence end (H, M, P, B, B).

Total time is: $T = 3T_H + 2T_P + 4T_B + 2T_M + 6T_K$

Total time is: $T = 3{\times}0.4 + 2{\times}1.1 + 4{\times}0.1 + 2{\times}1.2 + 6{\times}0.28 = 7.88\text{sec}$

Easy to model & accurate.

Only for expert users & doesn't model poor usability.

Doesn't model learning time & errors.

Fitts' Law

A better **model for pointing/selection movement time which considers distance, size and device.** Works with most pointing devices. *e.g. fingers, mouse, joystick & foot.*

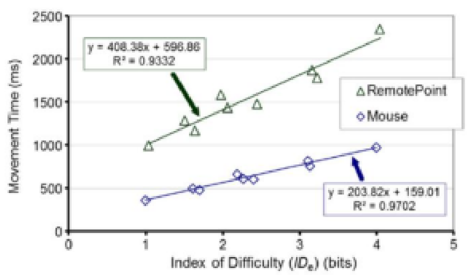
- Increases with distance to target.
- Decreases with size of target.
- Based on rapid, aimed movements.
- Doesn't work for touchscreens.

$$MT = a + \overset{\text{IP = "Index of Performance" = 1/b}}{b}\ \underbrace{\log_2\left(\frac{D}{W}+1\right)}_{\text{ID = "Index of Difficulty"}}$$

- MT - Movement Time.
- D - Distance between start and target centre.
- W - Target width.
- a and b are input device characteristics.

Example

Content and pie menus align well with Fitts law!



- High R^2 means both conform to fitts law.
- b is the slope.
- $\frac{1}{b}$ - the throughput.
- Mouse is faster and has higher throughput.

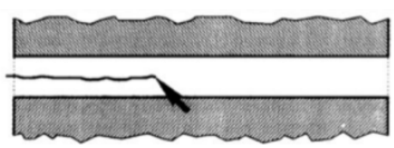


Figure 1: Self-paced movement with normal con straint

Steering Law

An adaptation of Fitts' law which calculates time to steer between boundaries.

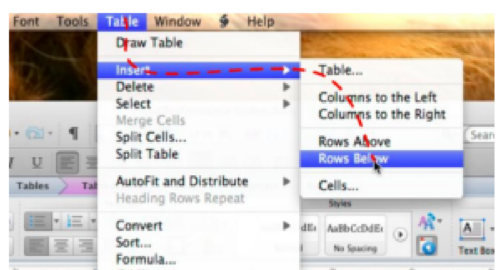
$$MT = a + b \times \frac{A}{W}$$

- A - tunnel length.
- W - path width.
- ID is now linear not logarithmic.

Example: Hierarchical Menus

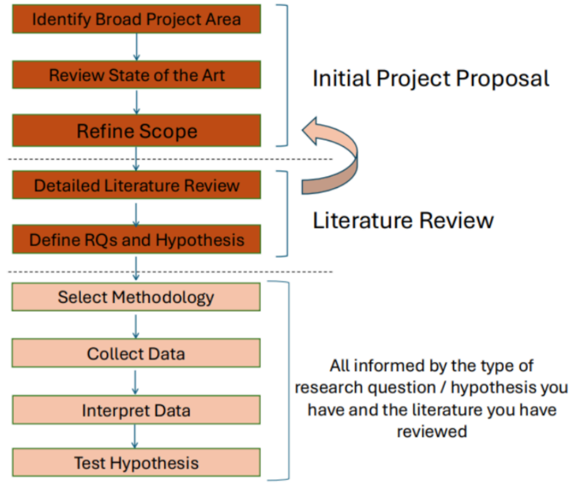
Sum the parts of the path:

1. Wide Path - Fitts' Law
2. Narrow Path - Steering Law
3. Wide Path - Fitts' Law



Experimental Design & Methodology

Steps for developing a research study:



Identifying Research Topics & Literature Review

Good research topics are **novel**, **useful** (applicable to other projects) and **scientific** (clear, reproducible and evidence-based).

Finding Related Work

Use search engines (*e.g. Google Scholar*) and organisation-specific digital libraries (*e.g. ACM*) to **gather relevant papers** with:

Keyword Search

Snowball Search: Follow up references.

Then filter out irrelevant ones using the abstract.

Peer Reviewing

Means **other experts have reviewed publications for inconsistencies, presentation and completeness**. They often request changes. Individuals are anonymous but the board of possible reviewers is known.

Reading Papers

Use the **three-pass approach:**

1. Read the title, abstract, intro, headings and conclusions. Answer the 5 Cs: Category, Context, Correctness, Contributions, Clarity.

2. Read it with care and jot key points in the margin. Ask questions like: are axes properly labelled? Do results have error bars? Summarise main contain with supporting evidence at the end.

3. Challenge every statement and jot down ideas for future work. Should be able to reconstruct the entire paper from memory.

Research Questions & Hypothesis

Use the l**iterature review to create a research question & hypothesis which are clear, concise, general and replicable**. There are different types and multiple can be tackled!

Follow an **Empirical Approach:** Replicable, clearly defined and falsifiable.

e.g. "What is the relationship between positive emotions and presence in VR?"

Study Design

Outlines the structure and strategy of the research study. Needs to be **ethical** and **scientifically rigorous**. Influenced by resources, previous research, researcher's attitude and the aim.

Study Types

Experimental: Manipulation of participants into different conditions. *E.g. VR headset VS screen.*

Quasi-experimental: Uses naturally occurring groups. *E.g. people who own VR VS don't.*

Correlational: Explores if variables are associated. *E.g. Within VR owners, does years owned correlate with immersion?*

Group Types

1. **Within-subject (Paired):** One group compared across time/circumstance.
2. **Between-subject (Unpaired):** Multiple groups being compared on some outcome. Each has a different configuration of the independent variables.
    a. **Different:** Individual differences between groups can be a problem.
    b. **Matched:** Participants between groups are paired by characteristics to reduce variability.

Variables

- **Independent:** Manipulated through design. *e.g. immersive medium with two levels: VR & AR headset.*
- **Dependent:** Expected to change as a result of independent variables. *e.g. enjoyment and presence*.

Two independent variables with 3 and 2 levels respectively means there are 6 (3*2) conditions!

Pilot Studies

A smaller, controlled study before an empirical one. To **test the feasibility of answering the RQ**, **ensure apparatus works**, **instructions are clear** and **fine-tune study design**.

Theoretical Research

Uses **theory as evidence** for arguments about expected observations.

Empirical Research

Primary data is collected and analysed based on direct observation. Arguments are made on the basis of empirical evidence rather than theory. *e.g. Is algorithm A more efficient than algorithm B, in practice?*

Internal Validity: The extent which changes in the dependent variables are in response to changes in the independent variables.

External Validity: How generalisable the result are to other systems, devices,people, contexts, etc.

Internal validity eliminates alternative explanations for your results. External validity helps to generalise them to the wider population.

Lab Studies	*Field Studies*
• **More Control/Internal Validity:** Avoids contaminating the experiment with confounding variables. • **Less Realism/External Validity:** Difficult to apply findings to real-life.	• **Less Control/Internal Validity.** • **More Realism/External Validity.**

Threats to Validity

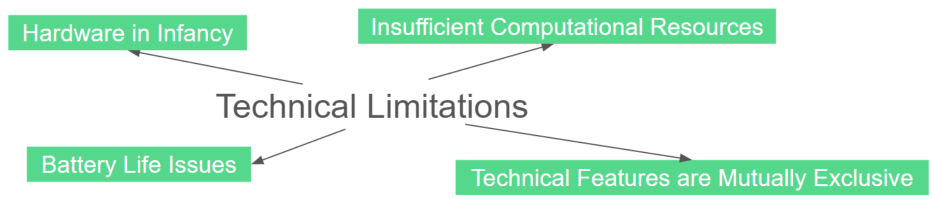
3 X 3 Latin Square

A	B	C
B	C	A
C	A	B

1. **Confounding Variables:** Uncontrolled variables that impact the study.
2. **Order Bias:** Order of tasks affects the dependent variables.
   Solution: Counterbalance using a latin square for the variables or between participant design.
3. **Training Effects:** Experience and learning rate impacts participant performance.
   Solution: Training or screening before tasks.
4. **Fatigue:** Participants getting tired.
   Solution: Breaks, task limits, counterbalancing.
5. **Participant or Facilitator Misunderstanding:** Different interpretation leading to different performance.
   Solution: Define precisely in the script.
6. **Social Desirability/Acquiescence Bias:** Participants do what's socially expected, without being honest.
   Solution: Diversification and screening.
7. **Drop-outs**
   Solution: Acknowledge limitations and report.
8. **Interaction Between Participants:** May light to competition, imitation or demoralisation.
   Solution: Minimise interaction and request non-disclosure.
9. **Hawthorne Effect:** Participants know they're in an experiment, so modify their behaviour.
   Solution: Longitudinal study, being discrete in observations.

Virtual Reality

VR is relatively **new**, has a **small user-base** but **great potential**. **Presence is vital for user engagement**, which depends on technical, user and interaction factors. VR isn't equally engaging for everyone.



Individualised & Dynamic Experiences

Users are the key to engagement, not hardware, so adapting content to the user's emotions, traits and behaviour is ideal!

- Custom content even in shared VEs.
- Easier to measure affect, traits and behaviour.
- Making it accessible increases the user base.
- Potential "killer" feature.
- Current hardware limitations. *e.g. sensors*

Embodiment of Avatars

Embodiment: The sensation of owning and being in control of/located within one's own body.

People can feel embodiment with external entities like avatars! Avatars are a self-representation in a virtual environment and the **proteus effect** describes how their features impact our attitude, behaviour and cognition. Avatar personalisation and motor control enhances embodiment and emotion!

Introduction to Data Analysis & Presentation

HCI is a **natural science** which involves measurement and evaluation, affecting safety, efficiency, etc. Effective data presentation facilitates digestion and understanding.

Data Types

<table>
<tr><td colspan="2">Qualitative/Categorical
Descriptive and categorical.
Analysis is interpretive.
Output: Word & images.</td></tr>
<tr><td>Nominal
Set of named attributes.
Unordered.
e.g. VR headset brand & opinions.</td><td>Ordinal
Cannot average.
Ordered.
e.g. clothing size: XS, S, M, L, XL</td></tr>
</table>

<table>
<tr><td colspan="2">Quantitative/Numerical
Measurable.
Analysis is statistical.
Output: Numbers, statics & graphs.</td></tr>
<tr><td>Discrete
Discrete rating scales.
e.g. cybersickness rating.</td><td>Continuous
Continuous rating scales.
Could be a ratio.
e.g. pupil diameter.</td></tr>
</table>

Ratio Scale

The difference between an experiment and the baseline.

$$Ratio = \frac{A}{B}$$

- A is the experimental result.
- B is the baseline.

e.g. calculating changes in accuracy in video games.

Data Analysis

Should utilise machine learning! There are two methods:

Parametric	***Non-Parametric***
Used with numerical data. *e.g. normal distribution, pearson correlation analysis, t-test, ANOVA*	Used with numerical and categorical data. *e.g. permutation, chi-squared test.*

Data Presentation

Feature	Bar Chart	Boxplot	Violin Plot
Type of Data	?	?	?
Shows distribution?	N	Y	Y
Shows means?	Y	N	N
Shows Outliers?	N	Y	Y
Best Use Case	Comparing means/counts	Summarizing data distribution & detect outliers	Visualizing full distribution

The **state-of-the-art** presentation method is to recreate it in the reader's mind using first-person techniques, **interactive and immersive methods**. For example, looking at a glass brain in VR which shows brain activity!

Data Presentation

As discussed, there are three presentation techniques. Violin plots are the main focus.

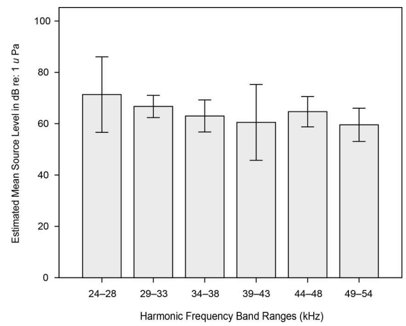
Bar Chart

If there are lots of individual results, calculate the mean and plot them. Also calculate the standard deviation and place it as an error margin at the top of each bar. Also:

- Label axis w/ units.
- Give a title.

$$S_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

n = The number of data points
x_i = Each of the values of the data
$\bar{x}$ = The mean of x_i



Violin Plots

Combine boxplots and kernel distributions.

Quartile Formulae

The **positions** of the quartile numbers are:

The Quartile Formula For Q1 $= \frac{1}{4}(n+1)^{th}$ term

The Quartile Formula For Q3 $= \frac{3}{4}(n+1)^{th}$ term

The Quartile Formula For Q2 $=$ Q3 – Q1 (Equivalent to Median)

IQR & Outliers *Don't do this in the exam!*

Subtract the **values** for Q_3 and Q_1:

$$IQR = Q_3 - Q_1$$

Then calculate the lower upper and lower bounds.

$$Lower\ Bound = Q_1 - 1.5 * IQR \quad Upper\ Bound = Q_3 + 1.5 * IQR$$

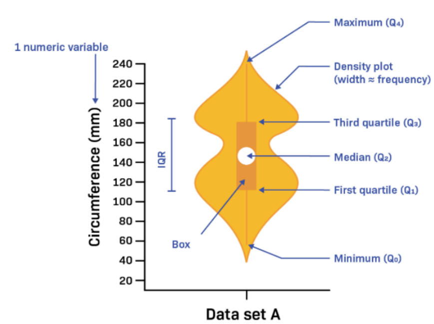
Classify values outside of this range as outliers and update the max & min accordingly.

Binning

Group values together for the kernel density estimation. Pick appropriate bins.
e.g. [1,2), [2,3), [3,4)...

Drawing Violin Plots

1. Organise the data in ascending order.
2. Plot and label the axis w/ units.
3. Title the graph.
4. Order the data in ascending order.
5. Draw the boxplot.
    a. Write the min & max.
    b. Calculate the quartile values, IQR, LB & UB.



    c. Find any outliers (these will be points) & update max & min.
6. Draw the kernel distribution using binning.

Case Study: The Glass Brain

Collects data from EEG, MRI and fMRI. Process and render them using Unity3D and VR. Helps viewers to interpret and process information:

- **3D Real-Time Brain Rendering:** Shows brain structure.
- **Colour-Coding:** Represents connectivity strength.
- **Animation:** Depicts real-time signal transmission.
- **Layering & Transparency:** Highlights different neural regions.

Parametric Data Analysis

Assumes the data follows a **known distribution** (*e.g. normal dist.*) with fixed **parameters** (*e.g. mean & standard deviation*).

Populations & Samples

Population: All individuals the study aims to analyse.

Sample: A subset of the population to represent the population in analysis.

Samples should be random with one for each condition to enable comparison!

Hypothesis Testing

Determines whether there is enough evidence to support a given assumption/hypothesis about a dataset. Used in parametric & non-parametric.

- **Null Hypothesis (H_0):** Assumes no effect or difference, deviation is because of chance.
- **Alternative Hypothesis (H_1):** Suggests there is a difference.
- **Significance Level (α):** How likely the data is if H_0 is true. Typically 0.05, indicating a 5% chance of incorrectly rejecting H_0.
- **Select a Test:** Can be parametric (*e.g. t-test or ANOVA*) or non-parametric (*e.g. chi-squared*).
- **Calculate the p-value (p):** Measures how much the sample deviates from H_0.
- **Compare with α:** If $p < \alpha$, reject H_0, if not then don't reject it.

Hypothesis Testing

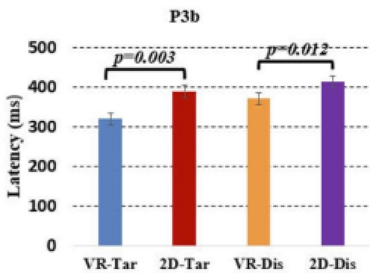
- **Type 1 Error:** Rejecting H_0 when it's true. Reduce the chances by **reducing** α.
- **Type 2 Error:** Not rejecting H_0 when it's not true. Reduce the chances by **increasing sample size**.

T-test

Compares **two sample means** to find how **likely their difference** is given they're from the same population. **Assumes the data follows a normal distribution**.
e.g. testing if a UI is better before and after modification

One-tailed	***Two-tailed***
Tests for a difference in a **specific direction**, so only use if you know there is a difference and want to understand the trend! *e.g. group A's mean is greater than group B's*	Tests for **any difference**, so use if you're unsure. *e.g. group A's mean is different from group B's.*

Independent/Unpaired	*Paired*
Compares data from separate groups (**between-subject**).	Compares data from the same group (**within-subject**).



Reporting Results

Plot the mean results of the group for each condition on a bar chart. Then, display your t-test results above the compared groups.

$DoF = no.\ of\ pairs\ -\ 1$

e.g. if sample size = 20, DoF = 19

Analysis of Variance (ANOVA)

Compares means across **three or more groups** (*e.g. VR, 2D or curved 2D*) to determine if any of them significantly change the dependent variable. It tests **multiple independent variables** to see their individual (main) and combined (interaction) effects on a dependent variable. **Assumes normality**, **standard ANOVA for between-subject.**

Repeated measures ANOVA is useful for **within-subject**. *i.e. if the same participants are tested at multiple points*

For example, for independent variables sex (male/female) and age (young/old) it assesses: Does sex affect usability? Does age affect usability? Or does the effect of age depend on sex?

Reporting Results

n^2 is the **effect size.**

- 0.01 = small.
- 0.06 = medium.
- 0.14 = large.

Generalised Linear Mixed Models (GLMMs)

Analyses **non-normally distributed data**, like gamma, poisson and binomial distributions, with **fixed and random effects.** They try to determine how fixed factors impact the dependent variables, accounting for random factors.

Data Distribution	Examples in HCI	Types of Data
Gamma (How much time is required until a random event occurs?)	You are designing a new VR typing UI and want to measure how long it takes users to complete a typing task and evaluate its efficiency. You observe that most young users finish quickly, but a few older users take much longer.	All type of quantitative data (but must be positive values)
Poisson (The counts of discrete events, in theory, no upper limit)	the number of emails received in a day	must be non-negative integer (e.g., discrete numerical data)
Binomial (The counts of discrete events, but there is an upper limit)	The motion sickness scales: 0-20)	Integer from 0 to *n*, where *n* is a fixed positive value (e.g., discrete rating scales.)

Fixed Factors
Independent variables. *e.g. age, sex, etc.* Their impact on the dependent variables are **fixed effects**.

Random Factors
Uncontrolled variables *e.g. participant IDs (for randomly sampled individuals), gaming experience, etc.* Their impact on the dependent variables are **random effects**.

Reporting Results
Report fixed and random effects on the dependent variables, alongside the supporting hypothesis tests.

Values used to calculate these:
- $df1 = k - 1$, where k is the number of groups.
- $df2 = N - k$, where N is the number of observations.

Non-Parametric Data Analysis
Doesn't assume any distribution of data.

X^2 Chi Square
Used to compare **nominal data**, names without order (*e.g. yes or no*), in **between-subject design** with multiple **groups/conditions** because it assumes independent observations.

For example, conducting a motion sickness experiment on three types of environment: visual, vestibular, visual & vestibular, and asking "Did you experience motion sickness?"

Degrees of Freedom

$$df = (r - 1)(c - 1)$$

where:
- r - independent variable levels.
- c - dependent variable categories.

Non-Parametric Alternatives
Alternatives tests with encoded ordinal or numeric data which **don't assume normality.**
- Independent t-test -> Mann-Whitney U Test
- Paired t-test -> Wilcoxon Signed-Rank Test
- ANOVA -> Kruskal-Wallis Test
- Repeated Measure ANOVA -> Friedman Test

Memorise!

Permutation Testing
Used to compare continuous ratio data for all types of study designs.

e.g. evaluating mobile app interface effectiveness.
1. Measure task completion time for both interfaces.
2. Average the batch for each and calc. difference.
3. Count how many of 10000 permuted mean differences were >=4.4.
4. $p = \frac{counts}{10000}$, compare with significance level.

Correlation Analysis

Measures the **direction** and **strength** of a relationship between two variables. Can be used in within & between-subject.

Datapoints must be **independent**. So, they must be averaged where there are multiple trials in within-subject.

Pearson Correlation

Measures **linear correlation**, assumes **normality** and works for **continuous** values. *e.g. typing speed vs error rate.*

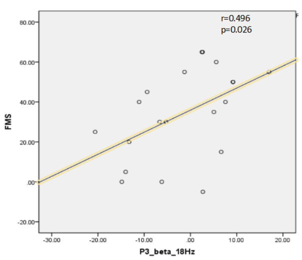
Spearman's Rank

Measures **monotonic correlation**, **doesn't assume normality** and works for **encoded ordinal** values. *e.g. satisfaction level vs task difficulty.*

e.g. if you have a set of values like 3.5, 7.3, 2, 13 you would rank order them: 2, 3, 1, 4 before using the same formula for pearson.

Regression Analysis

Explains and predicts the value of one variable based on another. Can be used in within & between-subject.

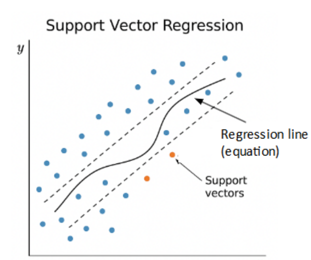


Linear Regression

Gives an equation to model the relationship. In between-subject design, each participant is a data point. In within, you should again average repeated trials.

Support Vector Regression

Applies a kernel to transform the data into higher dimensions, making it easier to linearly separate.



VR in Serious Games

"Serious games" have purposes beyond entertainment. *e.g. helping people with alzheimers to enhance cognitive control*

Camera perspective affects immersion and engagement. There are three types:

- Side-scrolling.
- Third-person.
- First-person.

VR should use a first-person but cybersickness may necessitate a 3rd-person perspective!

Why Use Virtual Reality?

VR increases **attention level** compared to a 2D monitor for at least 30 minutes!

Very immersive & engaging! | Can be used by all ages! | Wide range of applications!

Adaptive Game Difficulty

Use the **staircase algorithm**: a 1-up/3-down ratio based on EEG neurofeedback or other metrics.

1. Establish the person's normal EEG level through a **thresholding session**.
2. While using, measure their attention level using the EEG.
    a. If it exceeds a threshold, increase the game difficulty by 1.
    b. If it is below, decrease it by 3.

e.g. changing the time limit to completing a task by 10% and 30%

Design Principles

The purpose of the game should dictate:

- Story.
- Mechanics.
- Difficulty.
- User Interface.
- Side Effects.

For example, if this is targeted towards treating a medical condition, the story will be structured to the therapeutic target, the duration is the duration of treatment and the UI is the delivery method.

XR Platforms with Brain-Computer Interface (BCI) Integration

The **state-of-the-art XR platform**. BCIs facilitate the integration of EEG tracking and neuromodulation with XR/VR/MR. Neuromodulation is the modifying of brain waves to impact the user. (*e.g. prevent fatigue*) Steps to develop a BCI system:

1. **Hardware Prototyping:** Circuit design and firmware dev.

2. **Software Prototyping:** Integrate a LabStreamingLayer (LSL) to analyse EEG signals, identify biomarkers for certain events and feelings like fatigue, and respond with neurofeedback or neuromodulation.
3. **Validation:** Check it works.

Advantages

EEG can identify **biomarkers** and associate them with events or feelings. Then, **neuromodulation** can be delivered to deliver **counter-signals** to disrupt these biomarkers. If neuromodulation causes side effects for some, they can be given **neurofeedback** to help them **regulate their own brain activity**.

- Open-loop/One-way BCI
  - Real-time brain state tracking.
  - Real-time brain state writing/intervening.
- Closed-loop/Two-way BCI
  - General: Identifies group-level biomarkers and applies group-level neuromodulation.
  - Personalised
- Neurofeedback/self-regulated

If asked about this, go through these 5 keywords and then give use case examples.