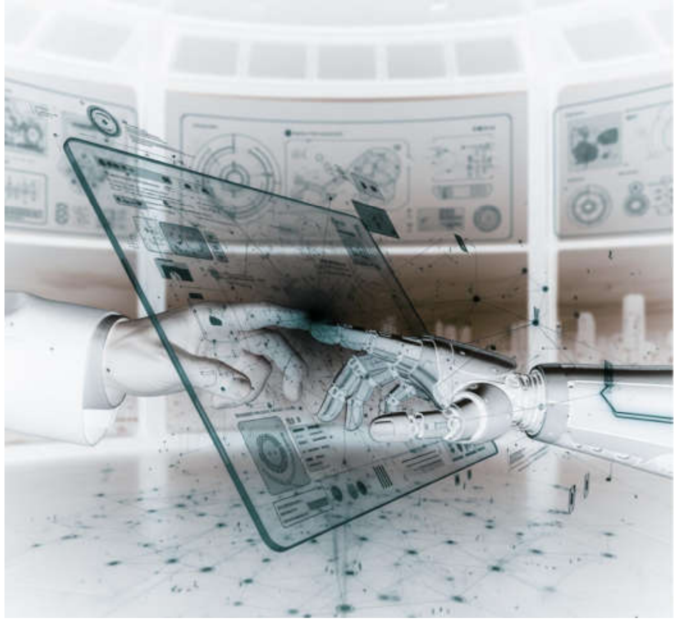


Human-Machine Interaction

# Human Factors


**Dr. Patrick Chan**
patrickchan@scut.edu.cn
South China University of Technology




# Human Factors in HMI

- **Human-Machine Interaction** focuses on human and machine interactions
  - Human factors are easily be ignored in traditional systems
  - Goal: Design interfaces that **accommodate human capabilities and limitations**, rather than forcing humans to adapt to machines
- Before discussing how to design a system, we need to **understand humans**



# Do you understand human?

**Scenario 1**


**Scenario 2**


- Same Inputs, but Different Outputs
- What happens?



# How do we understand human?

- Humans are highly diverse
- Even worse, human behaviors are context-dependent and inconsistent
  - Not a computer
  - Influenced by fatigue, emotion, bias, …
- How can we systematically understand humans?

# How do we understand human?

- **How do we analyze a complicated world?**
  1. Break into small components based on structure or function
  2. Focus on one component at a time
  3. Observe outputs under different inputs many times
  4. Infer the internal mechanism (go back to 3 for verification)
  5. Reconstruct the overall system
  6. Analyze the interactions between components
- This process is called **Model Building**



# How do we understand human?

- **Build human models**
  - Formulate human behavior as a model
    Process of perceive, decide, and react
- Even though models cannot fully represent human behavior, they help us understand and design systems better.



How do we understand human?

# Model Human Processor (MHP)

- Formulaic Approach to analyze Human Reaction
  - Developed by Card, Moran, and Newell (1983)
- Humans process information like a computer system with:
  - **Input**
    **Perceptual System**: Sensors (Eyes/Ears) + Buffers
  - **Process**
    **Cognitive System**: Central Processor + Memory
  - **Output**
    **Motor System**: Execution (Hands/Voice)



How do we understand human?

# Model Human Processor (MHP)

- Used decades of experimental data to calculate the decay time and processing speed for each system
- **Reaction Cycle**
  - Perceptual ≈ 100ms
  - Cognitive ≈ 70ms
  - Motor ≈ 70ms
- **Reaction Times**
  ≈ 100+70+70 = **240ms**

How do we understand human?

# Model Human Processor (MHP)

- Reaction time (~240 ms) is an **average** value
- Reaction time varies significantly among individuals
- Reaction time can be significantly improved through training



How do we understand human?

# Model Human Processor (MHP)

- **Design Implication**
  - Given Perceptual ≈ 100ms
  - **Instant response:**
    Responds faster than 100ms
  - **Delay response:**
    Responds slower than 100ms



# Key Factors of the Model

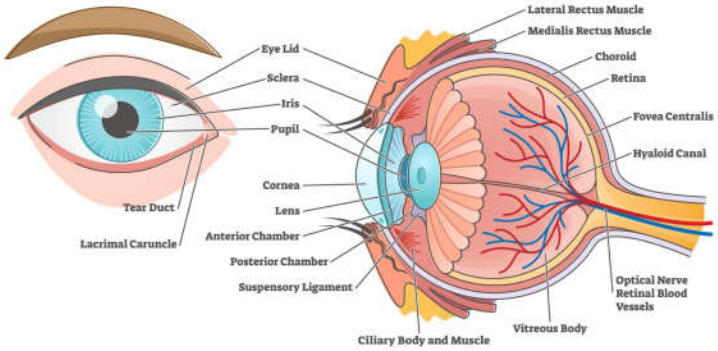
- **Input:** Sensory Systems
  - Vision + Touch
- **Processor:** Memory & Cognition
  - Short/Long Term Memory + Cognition + Attention
- **Output:** Reaction & Motor Control



# Sensory Systems

Sensory Systems
# Vision

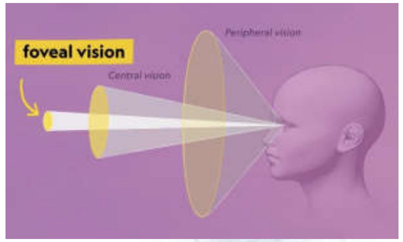
- Vision is the dominant sensory modality in human perception (Frequently cited as over 70%)






Sensory Systems: Vision
# Visual Field

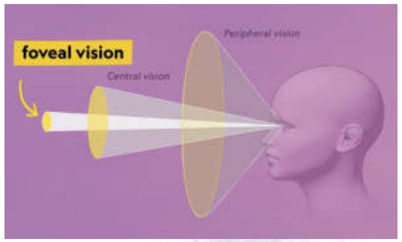
- **Foveal Vision (2°)**
  - Very sharp vision. Used to see small details and colors clearly
  - E.g. Checking a specific icon on the dashboard
- **Central Vision (15°)**
  - Used to focus on important objects and read information
  - E.g. Watching the car in front of you
- **Peripheral Vision (70-90°)**
  - Wide-angle vision. Cannot see details well, but very sensitive to movement and flashing
  - E.g. Sensing a car entering from a blind angle






Sensory Systems: Vision
# Visual Field

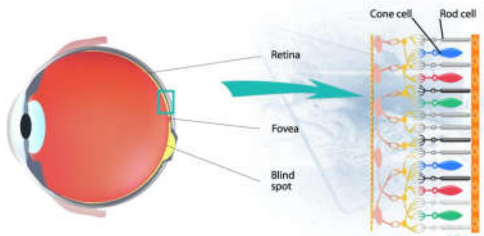
- **Design Implication**
  - Complex data must be in the center
  - Critical warnings should use motion/blinking to catch peripheral vision
    - Even not pay attention, peripheral may catch it






Sensory Systems: Vision
# Color Vision Deficiency

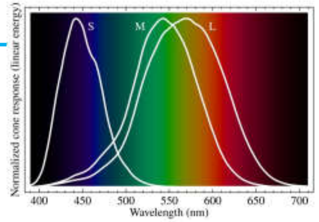
- **Cone**
  - Function best under bright-light conditions
  - Concentrated in the fovea, supporting central vision
    - **S (Short) Cones**: Blue
      Sensitive to short-wavelength light
    - **M (Medium) Cones**: Green
      Sensitive to medium-wavelength light
    - **L (Long) Cones**: Red
      Sensitive to long-wavelength light
- **Rod**
  - Responsible for low-light vision
  - Sensitive to light
  - Only light intensity

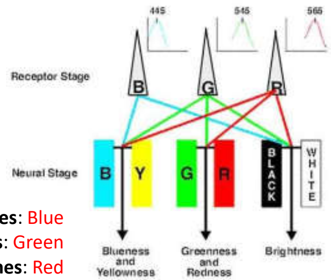


Sensory Systems: Vision

# Color Vision Deficiency

- **Red–Green Color Vision Deficiency**
  - L-cones or M-cones are nonfunctional
  - Common: 8% males VS 0.5% females
- **Blue–Yellow Color Vision Deficiency**
  - S-cones are nonfunctional
  - Rare
- **Total Color Vision Deficiency**
  - All cones are nonfunctional
  - Very Rare




**S (Short) Cones**: Blue
**M (Medium) Cones**: Green
**L (Long) Cones**: Red

Sensory Systems: Vision

# Color Vision Deficiency

- **Design Implication**
  - Never ONLY use color to convey information
  - E.g. "Delete" button
    - Shouldn't just be red
    - Also have an icon (trash can) or a text label




Sensory Systems: Vision

# Gestalt Principles

- **Gestalt** (form, shape in **German**)
  A group of **visual perception principles** developed by German psychologists in 1920s
  - 2 > 1 + 1
  - An **organized whole**, is perceived as greater than the **sum of its parts**

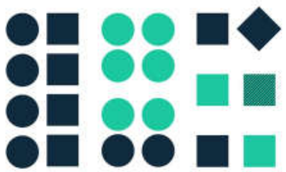


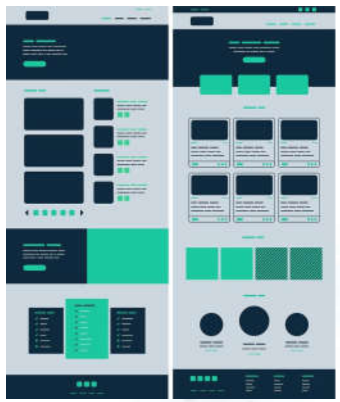
https://medium.muz.li/gestalt-principles-in-ui-design-6b75a41e9965

Sensory Systems: Vision: Gestalt Principles

# Similarity

- **Look similar = related**
- Groups similar elements into patterns
- **Design Implication**
  - Use similar style to group related items
  - Helps users understand function quickly





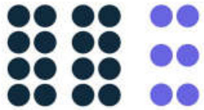
## Sensory Systems: Vision: Gestalt Principles
# Symmetry

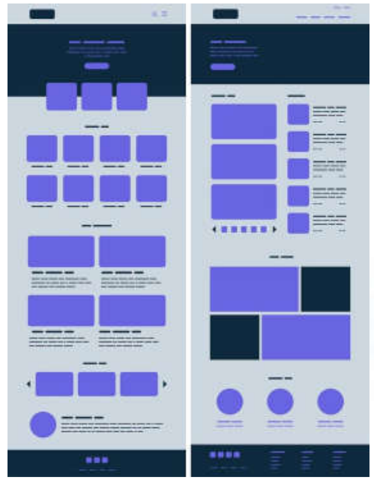
- **Balance = Visually Comfortable**
- Supports visual harmony and focus
- Clear and easy to understand
- **Design Implication**
  - Symmetrical layouts



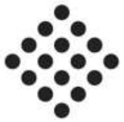
## Sensory Systems: Vision: Gestalt Principles
# Proximity

- Groups nearby items into one unit
  - Close together = related
  - Farther apart = separate
- **Design Implication**
  - Group related information together
  - Separate unrelated items clearly
  - Use spacing to organize content and reduce clutter





## Sensory Systems: Vision: Gestalt Principles
# Many Other Principles



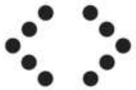
### Good Figure
Objects groupped together tend to be perceived as a single figure. Tendency to simplify.

### Proximity
Objects tend to be grouped together if they are close to each other.

### Similarity
Objects tend to be grouped together if they are similar.

### Continuation
When there is an intersection between two or more objects, people tend to perceive each object as a single uninterrupted object.

### Closure
Visual connection or continuity between sets of elements which do not actually touch each other in a composition.

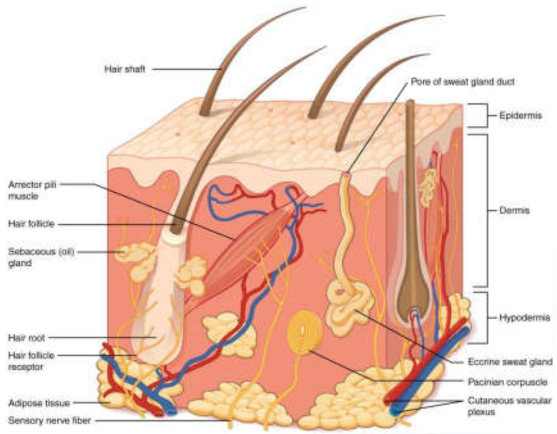


### Symmetry
The object tend to be perceived as symmetrical shapes that form around their center.



## Sensory Systems
# Touch

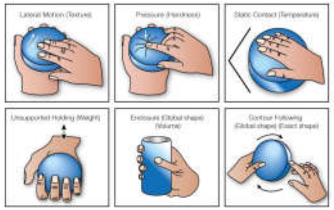
- The skin is the largest organ of the human body
- In adults, skin accounts for about 15–16% of total body weight



Sensory Systems: Touch

# Perception Type

- **Tactile**
  - Skin-based touch sensation
    - Surface-level sensations
    - Pressure, vibration, texture, and temperature
  - **E.g.** Smartphone vibration



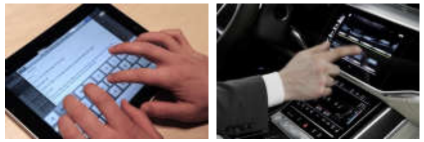
- **Haptic**
  - All touch-related sensation
    - Involves muscles and joints (kinaesthetic sense)
    - Touch + Movement + Force
  - Can simulate resistance, weight, or physical interaction
  - **E.g.** Gaming controller resisting movement
- **Tactile ⊂ Haptic**



Sensory Systems: Touch

# Perception Type

- **Tactile Feedback Example**
  - Short vibrations simulate the feeling of pressing a physical button
    - Audi Touch Response System
    - Typing vibration feedback on smartphones



- **Haptic Feedback Example**
  - Generates physical resistance or force
    - Surgical robots providing force feedback
    - Gaming steering wheel with resistance and vest



Sensory Systems: Touch

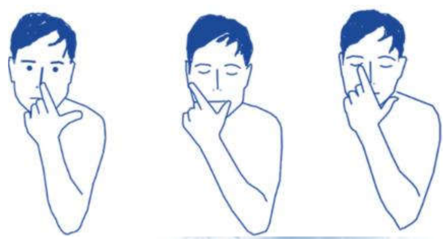
# Sensitivity

- Two-point discrimination
  - Fingertips: ~2 mm
  - Back: ~40 mm
- **Design Implication**
  - Touchscreen buttons must be large enough to account for the "Fat Finger" effect (minimum 7–10mm)


Sensory Systems: Touch

# Proprioception

- **Let's do this together!**
  - **Student A** closes his/her eyes
  - **Another student** touches one of his/her fingers
  - **Student A** is asked to use that finger to touch their nose
  - The test is repeated with different fingers on both hands



Sensory Systems: Touch

# Proprioception

- Position Sense, also "Sixth Sense"
- Ability to perceive its own position in space
  - Does not require vision
  - Comes from muscles, joints, and tendons
- Enable coordinated and balanced movement



Sensory Systems: Touch

# Proprioception Example

- Pressing **Brake Pedal**, you will feel
  - Resistance from the hydraulic system
  - Vibration during ABS activation
  - Stiffness change if something is wrong
- Turning **Steering Wheel**, you will feel
  - Road resistance
  - Tire grip changes
  - Vibration from uneven surfaces



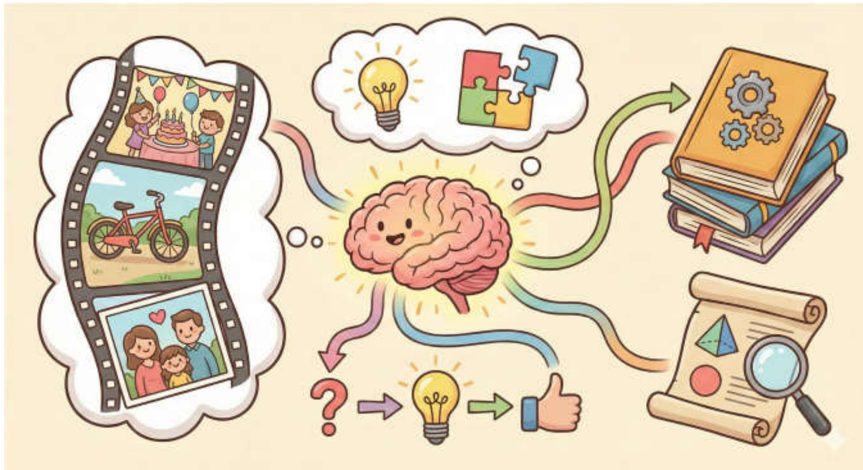
Sensory Systems: Touch

# Proprioception Example

- **Design Implication**
  - **Enable Eyes-Free Operation**
    - Critical controls should be usable without visual attention.
  - **Provide Force Feedback**
    - Use resistance, detents, and physical travel to enhance control awareness.
  - **Add Physical Boundaries**
    - Edges, textures, and shapes improve spatial recognition.
  - **Maintain Spatial Consistency**
    - Stable layout builds muscle memory



# Memory & Cognition



# Sensory Memory

- A **very** short-term storage system that briefly holds **raw sensory input** before further processing
- Extremely short duration
  - Visual (iconic): ~0.5s
  - Auditory (echoic): ~2–4s
- Large capacity but rapid decay
- Information is lost if attention is not applied





# Sensory Memory Example

- **Iconic Memory (Visual)**
  - **Sparkler Trail**
    - When you wave a sparkler in the dark:
      - You see a **continuous light trail**
      - But the sparkler is only at one position at each moment





# Sensory Memory Example

- **Iconic Memory (Visual)**






# Sensory Memory Exa

- **Echoic Memory (Auditory)**
  - Can you repeat that sound?

# Sensory Buffer

- **Design Implication**
  - Even if users perceive information, it will be lost if they do not attend to it.





# Short-Term Memory (STM)

- Acts as the brain's **temporary workspace** (like RAM in a computer)
  - Supports active thinking and information manipulation
- Fast access, but very limited capacity
  - **Limited capacity**: ~7 ± 2 items (Miller, 1956)
    - Modern research suggests the real limit is ~4 items
- Decays rapidly without attention
  - **Short duration**: ~15 – 20s





# Short-Term Memory Example

- **Dory**, Ready?






# Short-Term Memory Example

- **Dory**, Ready?

# Short-Term Memory

- Chunking
  - Grouping individual items into meaningful units memory capacity
  - 9 digits: 1 7 9 4 5 2 8 6 3
  - Grouped as: 179 – 452 – 863 or 17 – 94 – 52 – 86 – 3
- Elaborative Encoding
  - Making the information meaningful
  - When I was 17, my IQ was only 94, and I had just 52 dollars. I had to support my 86-year-old father and my 3 brothers.





# Short-Term Memory

- Design Implication
  - Do not display too many items at once (> 10)
  - Display less items for critical safety information (≤ 4)
  - Display only high-priority information by default
  - Group related items to support chunking
  - Use a clear hierarchical structure





# Long-Term Memory (LTM)

- A storage system for information retained over long periods of time
  - Like a hard-disk in a computer
  - Last from minutes to a lifetime
  - Strengthened through repetition and meaning
- Capacity is virtually unlimited
- Requires encoding and retrieval processes





# Long-Term Memory (LTM)

- Declarative (Explicit) Memory
  - **Semantic memory**: facts, concepts, meanings
    e.g., Paris is the capital of France
  - **Episodic memory**: personal experiences
    e.g., your first driving lesson
- Non-Declarative (Implicit) Memory
  - **Procedural memory**: skills and habits
    e.g., riding a bicycle, typing

# Long-Term Memory (LTM)

- How Information **Enters/Retrieval LTM**
  - **Encoding**
    - Repetition (rehearsal)
    - Meaningful association (elaboration)
    - Emotional connection
    - Practice and application
  - **Retrieval**
    - Cues improve recall
    - Recognition is easier than recall





# Long-Term Memory (LTM)

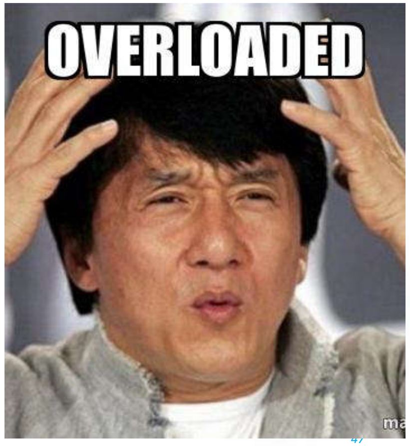
- **Design Implication**
  - Design should follow human norms and expectations
  - Use consistent layouts
  - Maintain standardized control positions
  - Reinforce through repetition and familiarity
  - Favor recognition over recall





# Cognitive Load

- **Amount of mental effort** required to process information
  - Limited by the capacity of **working (short-term) memory**
- Overload
  - Slower performance
  - Higher error rates
  - User frustration








# Cognitive Load

- **Intrinsic Load: Task Difficulty**
  - Inherent difficulty of the task itself (Unavoidable but manageable)
  - Determined by task complexity and user expertise
- **Extraneous Load: Poor Interface Design**
  - Caused by poor interface design
  - Unnecessary complexity, clutter, or unclear structure
- **Germane Load: Support Learning**
  - Mental effort devoted to learning and understanding
  - Supports schema formation and skill development

# Cognitive Load Example

- Booking a Ride in Mobile APP
  - Intrinsic Load
    - Decide: Pickup location, Destination, Ride type
  - Extraneous Load
    - Unclear icons, Pop-ups interrupting
  - Germane Load
    - Step-by-step flow (Pickup → Destination → Confirm)
    - Default suggestions (e.g., nearest pickup point)
    - Progress indicators



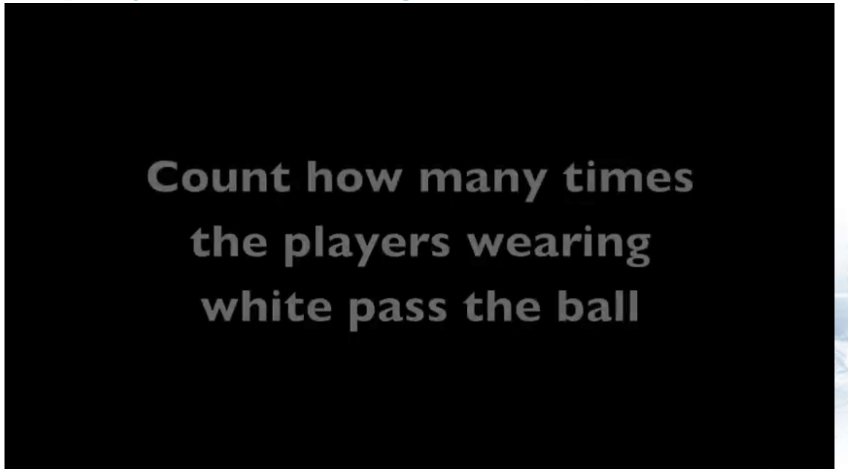



# Cognitive Load

- **Design Implication**
  - **Manage Intrinsic Load**
    - Break tasks into steps, provide guidance and cues
  - **Reduce Extraneous Load**
    - Simplify layout, use hierarchy and grouping, apply progressive disclosure
  - **Support Germane Load**
    - Encourage meaningful learning, reinforce consistent design patterns



# Count how many times the players wearing white pass the ball

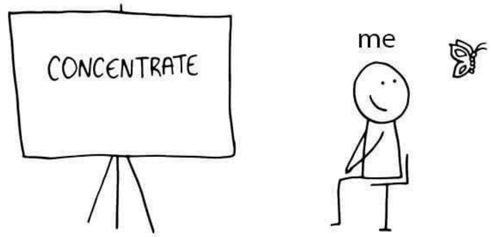







# Attention

- Attention is the process of selecting relevant information while filtering out distractions
- It determines what enters working memory



Memory & Cognition

# Attention Type

- **Selective Attention**
  - Focusing on one stimulus while ignoring others
  - E.g. Listening in Dr. Chan's Class


- **Divided Attention**
  - Attempting to perform multiple tasks simultaneously
  - E.g. Using a mobile phone while riding a bicycle




Memory & Cognition

# Attention Limit

- Human attention has a **limited capacity**
  - Limited cognitive resources
  - Working memory constraints
  - Time constraint
- Effects
  - **Attentional Blink**: Missing the second of two rapid events
  - **Inattentional Blindness**: Failing to see unexpected objects
  - **Divided Attention Cost**: Performance drops when multitasking



Memory & Cognition

# Attention

- **Design Implication**
  - **Reduce Distraction**
    - Avoid unnecessary alerts (animations or pop-ups)
  - **Highlight Critical Information**
    - Use visual saliency (contrast, color, size) and multimodal alerts (visual + auditory)
  - **Support Focus**
    - Group related information
    - Guide attention hierarchically



Memory & Cognition

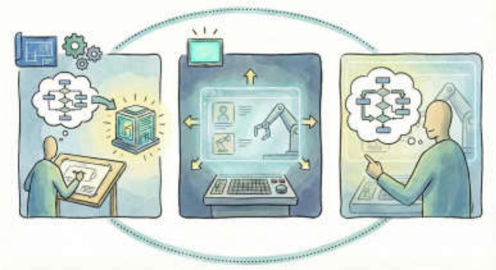
# Mental Model

- Users interpret the system according to **expectation**
  - Do not read manuals first
  - Rely on prior experience and assumptions
- **Mental Model**
  Users' internal understanding of how a system works
  - Help to predict outcomes and decide actions

Memory & Cognition

# Mental Model

- Problems arise when these models do not align
  - **Designer's Model**: How the system is intended to work
  - **System Image**: What the interface communicates
  - **User's Mental Model**: What the user believes is happening





Memory & Cognition: Mental Model Example

# Boeing 737 MAX — MCAS Case

- Boeing 737 MAX was developed as an updated version of the 737 series
  - Larger engines were installed
  - This changed the aircraft's aerodynamics
  - **At certain high angles of attack, the aircraft tended to pitch upward**



Memory & Cognition: Mental Model Example

# Boeing 737 MAX — MCAS Case

- To compensate, Boeing introduced **Maneuvering Characteristics Augmentation System (MCAS)**
- Its purpose:
  - Automatically push the nose downward
  - Make the aircraft "feel" similar to previous 737 models
  - Avoid costly pilot retraining



Memory & Cognition: Mental Model Example

# Boeing 737 MAX — MCAS Case

- **How MCAS Worked**
  - Activated automatically when a high angle of attack was detected.
  - Used data from **a single Angle-of-Attack (AoA) sensor** (in early design)
  - Could repeatedly trim the nose downward
  - Pilot input could be overridden if the system reactivated

# Boeing 737 MAX — MCAS Case

- **Pilot's Mental Model**
  - Aircraft behaves like previous 737 models
  - If the nose trims down unexpectedly, normal procedures apply
  - Automation assists but does not aggressively override
- **Actual System Behavior**
  - A hidden automation layer could **repeatedly** push the nose down
  - Triggered by faulty sensor input
  - Not fully documented in early training materials
  - Not clearly indicated as "MCAS" on cockpit displays
- **Mental Model Mismatch**





# Boeing 737 MAX — MCAS Case

- What Happened?
  - Faulty AoA sensor sends high AoA reading
  - MCAS activates → trims nose down
  - Pilots pull back → trim nose up
  - MCAS activates again → Repeated nose-down trimming
  - Nose down → descent
  - Acceleration
  - Loss of control





# Boeing 737 MAX — MCAS Case

- **Two crashes**
  - Lion Air Flight 610 (2018)
  - Ethiopian Airlines Flight 302 (2019)

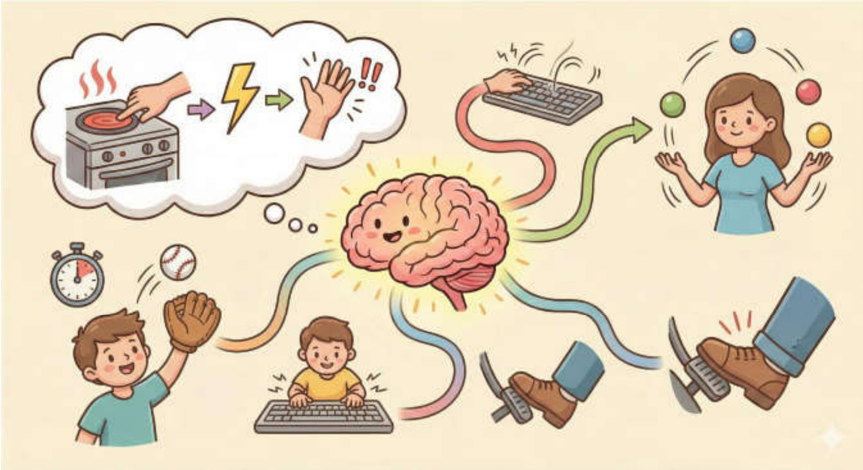




# Mental Model

- **Design Implications**
  - **Align with User Expectations**
    - Use familiar symbols and conventions
    - Follow platform standards
    - Make system status visible
  - **Reduce Misunderstanding**
    - Provide clear feedback
    - Avoid hidden system states
    - Keep behavior consistent

# Reaction & Motor Control

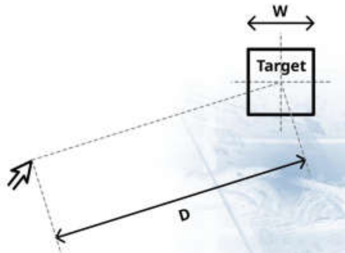




Reaction & Motor Control

## Fitts's Law

- Empirical human-performance model
- Predicts the time required to move to and select a target
- **$T = a + b * \log_2(1 + D/W)$**
  - T: Time to move
  - a, b: Empirical constants
  - D: Distance to target
  - W: Width (size) of target






Reaction & Motor Control

## Fitts's Law

- **Interpretation**: **$T = a + b * \log_2(1 + D/W)$**
  - Two Key Factors
    - **Distance (D)**
      Farther targets take longer to reach.
    - **Width (W)**
      Smaller targets require more precision and time.
- Larger and closer targets are faster and easier to acquire
  - Time increases logarithmically with distance and decreases with target width



Reaction & Motor Control

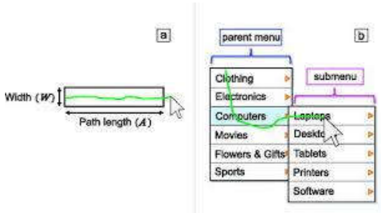
## Fitts's Law

- **Design Implication**
  - Make frequently used targets large
  - Place important targets near expected cursor/hand position
  - Avoid small, crowded interactive elements
  - Use screen edges and corners
    - Cannot go beyond the edge and corner
    - Easier and faster to hit
    - E.g. “Start” button in Windows

Reaction & Motor Control

# The Steering Law

- Predict the time required to move through a **constrained path or tunnel**
  - Extends **Fitts's Law** from point selection to **continuous movement**
- $T = a + b \int \frac{ds}{W(s)}$
  - T = movement time
  - W(s) = width of the path at position s
  - a, b = empirical constants




- Interpretation: Narrower paths increase movement time



Reaction & Motor Control

# The Steering Law

- **Design Implications**
  - Avoid narrow interaction paths
  - Increase width of hover areas
  - Add buffer zones between menus
  - Make movement paths smooth and continuous



Reaction & Motor Control

# Hick's Law

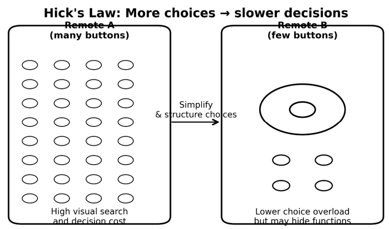
- Predict the time required to make a decision based on the number of available choices
- **$T = a + b * \log_2(n + 1)$**
  - T: Time to move
  - a, b: Empirical constants
  - n: number of choices
- **Interpretation**: More choices → longer decision time
  - Decision time increases with number of choices **logarithmically**



Reaction & Motor Control

# Hick's Law

- **Design Implications**
  - Limit the number of choices presented at once
  - Use hierarchy and grouping
  - Apply progressive disclosure
  - Highlight the most important option



# Human State

- Refers to the physical, cognitive, and emotional condition of a person at a given time
  - **Physical State**: Fatigue, Illness, Stress, Alcohol or medication
  - **Mental State**: Mental workload, Attention level, Frustration
- Directly affects human performance
  - Reaction time
  - Decision quality
  - Motor control





# Sensation & Perception

- Just because you can sense it does not mean you can perceive it
- **Sensation**
  - Detection of physical stimuli by sensory receptors
  - Raw input from the environment
  - E.g. Light hitting the retina
- **Perception**
  - Interpretation and meaning-making of sensory input
  - Brain organizes and explains what is sensed
  - E.g.: Recognizing a face





# Sensation & Perception

- **Design Implication**
  - Showing a warning does not mean the danger is the perceived
  - **Make Important Information Salient**
    - Contrast, Size, Motion, Multimodal cues
  - **Do Not Rely on Assumptions**
    - Provide clear feedback, Avoid ambiguous symbols, Ensure consistency





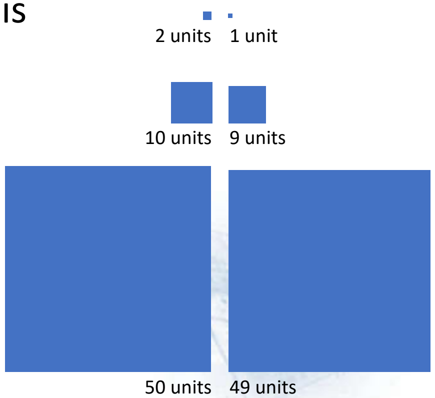

# Perceptual Discriminability

- Ability to distinguish one stimulus from another
- Aspects
  - Contrast (high vs low)
  - Size differences
  - Color separation
  - Spatial separation

# Weber's Law

- Just Noticeable Difference (JND) is proportional to the original intensity

- For Example
  - 1 unit change can be noticed?
    - Easy for 1 vs 2 units
    - Difficult for 49 vs 50 units








# Perceptual Discriminability

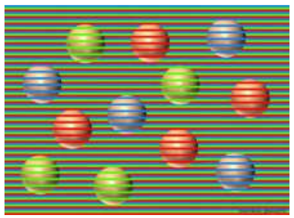
- **Design Implication**
  - Use proportional scaling
  - Ensure noticeable contrast differences
  - Avoid relying on tiny visual distinctions
  - Test discriminability in realistic conditions





# Illusions

- What color are the balls?



- Are the two lines the same length?

- Is this cat going up or down?

- The brain uses experience-based assumptions to interpret visual input





# Illusions

- **Design Implication**
  - Visual design can distort perceived performance
    - Trick a user into thinking a progress bar is moving faster
  - Avoid misleading contextual cues


https://www.giannisarcone.com/Muller_lyer_illusion.html
https://www.chrisharrison.net/projects/progressbars2/ProgressBarsHarrison.pdf

Human State: Sensation & Perception

# Perceptual Adaptation

- Sensitivity to a constant stimulus decreases over time
- The brain prioritizes **change**, not constancy.
  - Constant stimuli → reduced neural response
  - New or changing stimuli → increased attention




Human State: Sensation & Perception

# Perceptual Adaptation

- **Design Implications**
  - **Avoid Constant Stimuli for Critical Alerts**
    - Do not rely on persistent flashing
    - Use intermittent or escalating signals
  - **Highlight Change**
    - Motion and contrast should signal important updates
    - Avoid unnecessary constant visual noise



Human State

# Workload

- Demands placed on a user during task performance
  - Physical workload
  - Mental workload
- High workload, fatigue
- Low workload, boredom
- Both may increase errors




Human State

# Workload

- Workload is **not constant**
  - varies across different stages of a task
- Typical Pattern
  - **Initial phase:** Higher load (understanding, planning)
  - **Execution phase:** Moderate load (monitoring and adjustment)
  - **Critical moment:** Peak load (decision under time pressure)
  - **Post-task phase:** Reduced load or Recovery
- E.g. Cruising → low workload,  Emergency → peak workload

Human State: Workload

# Physical Workload

- Physical effort required to perform a task
  - Muscle force
  - Body movement
  - Posture
  - Endurance over time



Human State: Workload: Physical Workload

# Measurement

- Muscle activity (e.g., EMG)
- Heart rate and energy expenditure
- Posture, motion, and repetition rate




Human State: Workload

# Mental Workload

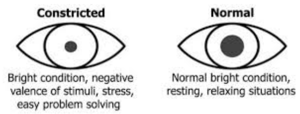
- Mental effort and cognitive resources required to perform a specific task
  - **Task Demand**
    How much attention, memory, decision-making, and time the task requires
  - **Mental Resource**
    The operator's available capacity, influenced by experience, fatigue, stress, and situation
- **Mental Workload ∝ task demands / mental resources**

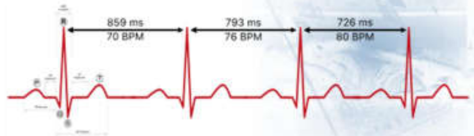


Human State: Workload: Mental Workload

# Measurement

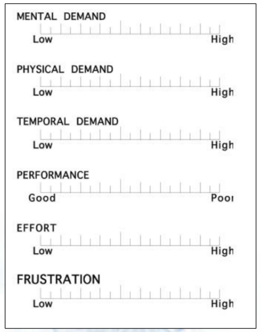
- Heart Rate Variability (HRV)
- Pupil Dilation (Eye-Tracking)
- Electroencephalogram (EEG)



# General Evaluation

- **Task Load Index (TLX)** proposed by **NASA**
  - **Mental Demand:** How much thinking/deciding was required?
  - **Physical Demand:** How much pulling/pushing/turning?
  - **Temporal Demand:** Was the pace slow or frantic?
  - **Performance:** How successful was the user in their own eyes?
  - **Effort:** How hard have to work to reach that level of performance?
  - **Frustration:** Did they feel stressed, annoyed, or discouraged?




- Each dimension is rated (typically 0–100)
- Overall workload score is computed from these ratings





# Workload

- **Design Implication**
  - Interface should be improved if workload evaluation is high
    - Offload tasks by Automation
    - Reduce the number of steps
    - Allow to control the speed of information flow





# Fatigue

- State of reduced performance caused by prolonged effort, lack of sleep, or sustained attention
  - **Physical Fatigue**: Muscle exhaustion
    - Reduced motor precision
  - **Mental Fatigue**: Reduced attention
    - Slower thinking, poor decision-making





# Effects of Fatigue

- **Reduced Situational Awareness:** Difficulty monitoring the environment
- **Inattentional Blindness:** Failure to notice unexpected events
- **Tunnel Vision:** Overlooking peripheral information
- **Peripheral Neglect:** Reduced sensitivity to side or background cues
- **Behavioral Regression:** Reverting to old or unsafe habits

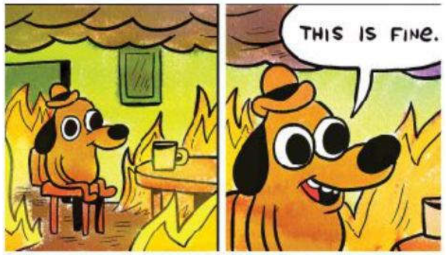
Human State
# Fatigue

- **Design Implication**
  - Simplify interface under high workload
  - Use clear, redundant alerts
  - Reduce unnecessary complexity
  - Support Detection
    - E.g. Fatigue alerts, Scheduled breaks



Human State
# Stress

- **Physiological and psychological response** to perceived pressure, threat, or high demand
  - Increased heart rate
  - Elevated arousal
  - Narrowed attention
  - Heightened emotional state

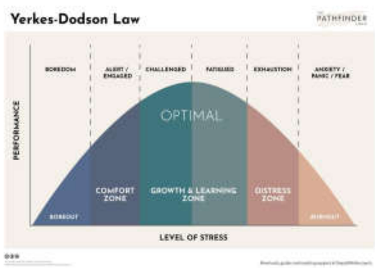



- **Is stress always bad?**



Human State: Stress
# Yerkes-Dodson Law

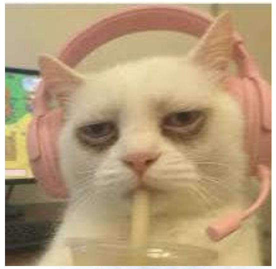
- **"Inverted-U" Curve**
  Performance increases with stress, but only up to a point
  - **Low stress** → Low alertness
    - Boredom leads to errors (complacency)
  - **High stress** → Performance decline
    - Panic leads to "System Crash" in the brain
  - **Moderate stress** → **Optimal performance**

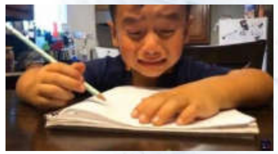





Human State: Stress
# Effects of Stress

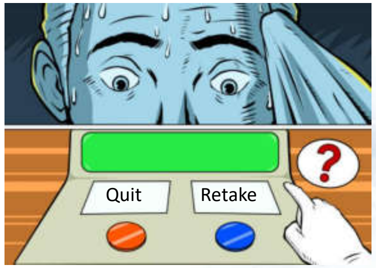
- **Cognitive Effects**
  - Narrowed attention (tunnel vision)
  - Reduced working memory capacity
  - Impaired judgment
- **Behavioral Effects**
  - Impulsive decisions
  - Slower or inappropriate reactions
  - Increased error rate





Human State
# Stress

- **Design Implications**
  - **Do not** design for calm and fully attentive users
  - Simplicity saves time and reduces errors in high-stress moments
    - No complex decision-making
    - Simplify critical interfaces
    - Highlight essential information
    - Reduce unnecessary options
    - Provide clear feedback






Human State
# Information Overload

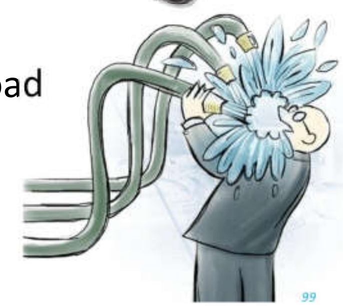
- Occurs when the amount of information exceeds a person's processing capacity
  - Excessive notifications
  - Complex dashboards
  - Multitasking demands
- **When Overloaded**
  - Slower decision-making
  - Increased error rate
  - Missed critical information

https://www.arngren.net/



Human State
# Information Overload

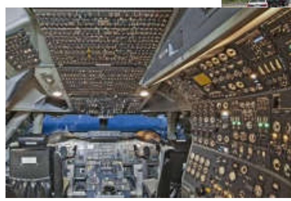
- **Firehose Effect**
  - Massive information flow
  - Extremely high speed
  - Exceeds human processing limits
- Even worse than information overload





Human State
# Information Overload

- **Design Implications**
  - **Reduce Extraneous Load**
    - Prioritize critical information
    - Use hierarchy and grouping
    - Apply progressive disclosure
  - **Guide Attention**
    - Use visual saliency wisely
    - Avoid competing alerts



# Multi-Tasking

- Perform **more than on tasks** simultaneously
  - Common in complex systems
- **Reality**
  - Our brains do not truly multitask
  - Switches attention between tasks
- **Consequences**
  - Workload Increase
  - Higher stress and fatigue
  - Greater risk of information overload






# Multi-Tasking: Attention

- Focusing less is not necessarily better
- **Why?**
- **Selective Attention**
  - Focus on one task
  - **Risk**: Missing other information (no big picture on the system)
  - **Best**: Critical Task
- **Divided Attention**
  - Focus on Multiple tasks
  - **Risk**: Delays
  - **Best**: Simple and well designed Tasks





# Multi-Tasking

- Number of Tasks is limited
  - Cognitive Constraints
    - Limited attention and memory
    - Switching requires reorientation time
  - Task-Switching Cost
    - Mental fatigue
- Easily if using different resources
  - **Easy**: Listen to music (Audio) while driving (Visual)
  - **Hard**: Reading a text (Visual) while watching movie (Visual)



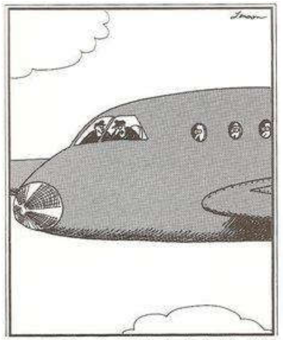



# Multi-Tasking

- **Design Implications**
  - **Reduce Task Switching**
    - Avoid simultaneous alerts
    - Support task completion before interruption
    - Use clear task boundaries
  - **Prioritize Critical Tasks**
    - Design for focus by suppressing non-urgent notifications
  - **Multi-modal feedback**
    - Spread the load

# Situation Awareness (SA)

- "**Knowing what is happening, why it is happening, and what will happen next**", by Endsley, 1995
  - **Level 1 - Perception**: Detect relevant information
    - E.g. Seeing a robot warning light
  - **Level 2 - Comprehension**: Understanding what it means
    - E.g. Knowing the robot is overheating
  - **Level 3 - Projection**: Anticipating future states
    - E.g. Predicting the robot may shut down



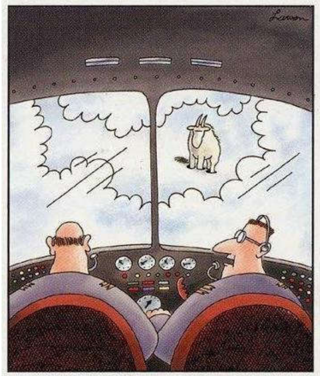
"The fuel light's on, Frank! We're all going to die! ... We're all going to die! ... Wait, wait. ... Oh, my mistake—that's the intercom light."





# Situation Awareness (SA)

- If the user loses Situation Awareness, they cannot control the system effectively
- **Causes**
  - Fatigue or stress
  - Information overload
  - Automation overreliance



"Say ... what's a mountain goat doing way up here in a cloud bank?"





# Situation Awareness (SA)

- **Situation Awareness Global Assessment Technique (SAGAT)**
  - by **Mica Endsley (1988, 1995)**
  - Indicate the system problems at a specific moment in terms of SA
  - Widely used in aviation, military, driving, robotics
- E.g. Consistently fail at Level 2,
  better data visualization is needed





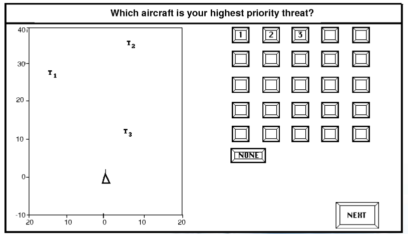
# Situation Awareness (SA)

- Procedure
  - A simulated task is running (e.g., flight, driving)
  - The simulation is randomly paused (freeze technique)
  - The display is blanked
  - Participants answer questions target the three SA levels about the current situation

Human State

# Situation Awareness (SA)

- Questions Example
  - **Level 1 - Perception**
    "What is the aircraft's altitude?"
  - **Level 2 - Comprehension**
    "Is the aircraft in a dangerous state?"
  - **Level 3 - Projection**
    "What will happen in the next 30 seconds?"






Human State

# Situation Awareness

- **Design Implication**
  - **Perception**
    - Clear, salient displays
    - Reduce clutter
  - **Comprehension**
    - Provide meaningful context
    - Use familiar symbols
    - Always provide a "Map" or "Status-at-a-glance" area
  - **Projection**
    - Predictive alerts
    - Trend indicators



# Human Error

- A failure of planned action to achieve the intended outcome
- Most human errors are induced by systems, not purely individual failures
  - Poor interface design
  - High workload
  - Fatigue or stress
  - Information overload


Human Error

# Error Type

- **Lapses**
  - Memory failure
  - E.g. Forgetting to complete a step
- **Slips**
  - Correct intention, wrong execution
  - E.g. Clicking the wrong button
- **Mistakes**
  - Wrong decision
  - E.g. Misinterpreting a warning
- **Violations**
  - Intentional deviation from procedure
  - Should understand why
  - E.g. Ignore warning

# Human Error

- **Design Implication**
  - Assume human errors will occur
  - Tolerant of human limitations

  - **Defense-in-Depth Principle**
    - Only one protection is risky (Each has weaknesses)
    - Develop multiple layers of prevention and protection
      - Catastrophe happens only when all defenses fail simultaneously
      - **Swiss Cheese Model**: “holes” in multiple defense layers align



# Human Error

- **Design Implication**
  - **Forcing Functions**
    - Prevents action unless specific conditions are met
    - Eliminates "Slips" and "Lapses"
    - For Example
      - Cannot take the car out of "Park" unless your foot is on the brake
      - Pressure two separated buttons at the same time to trigger Electric Paper Cutter



https://en.wikipedia.org/wiki/Swiss_cheese_model



Human Error
# Automation

- Can automation avoid human error?

- Change the error nature
  - **Less Practice**: More reliable automation, less practiced human
  - **Ignore Contradictory** : Tend to over-rely on automated suggestions and ignore contradictory
  - **Out-of-the-Loop (OOTL)**: No longer actively controlling the system, leading to a "mental logout“ and takes much longer to "wake up"

AUTOMATION BIAS



Human Error: Automation
# Trust Problem

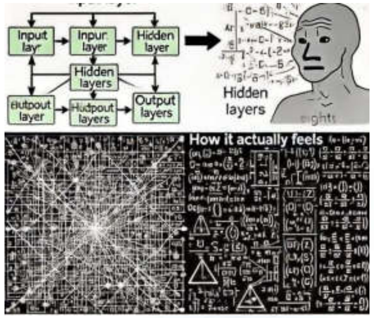
- **Over-Trust**: Complacency
  - Machine is perfect; I can take a nap.
  - Leads to safety risks
- **Under-Trust**: Skepticism
  - Machine is annoying; I'm turning it off.
  - Leads to high workload and wasted technology

Human Error: Automation

# Trust Problem: Calibration

- Trust is built on understanding
  - Avoid "Black Box"
- **Design Implication**
  - Keep the human informed, engaged, and capable of taking over at any moment.
  - For Example
    - Not just "Braking!", show “Obstacle Detected : Braking!"

**When someone ask you how you make a decision**






Case Study

# Three Mile Island Nuclear Accident

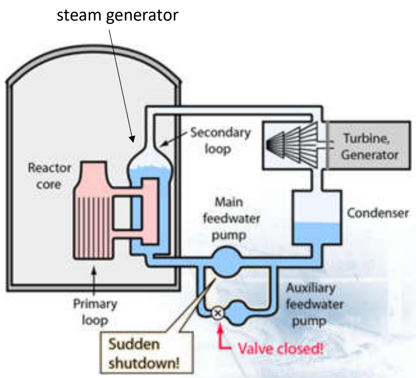
- Date:
  **March 28, 1979**
- Location:
  **Pennsylvania, USA**
- Unit involved:
  **TMI-2**
- Event:
  **Partial Core Meltdown**



Case Study

# Three Mile Island Nuclear Accident

- A problem occurred in the **Main Feedwater Pump**
  - **Steam generators** stopped receiving water
- **Auxiliary feedwater pumps** automatically started but failed
  - **Valves** were left closed after maintenance
- **Water level** in steam generator boils down

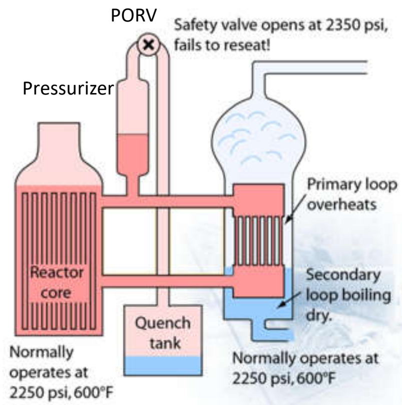





Case Study

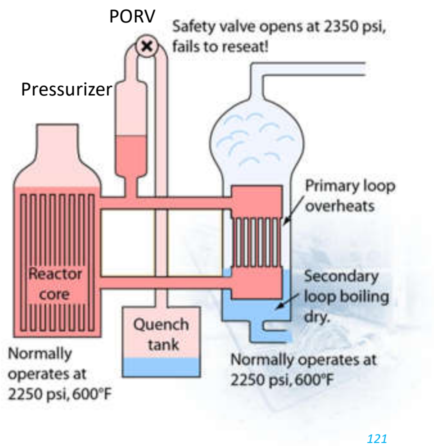
# Three Mile Island Nuclear Accident

- Steam generator boiling dry causes superheat **the primary loop**
- **Reactor coolant** pressure rises above 2350 psi
- Trigger **Pilot-Operated Relief Valve (PORV)**
- **Radioactive steam and water** move to quench tank



Case Study
# Three Mile Island Nuclear Accident

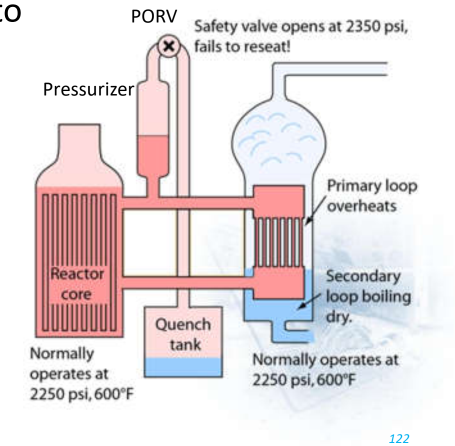
- High **reactor coolant** pressure also automatically triggered **a reactor trip (scram)**
  - **Control rods** were fully inserted to stop the nuclear fission chain reaction
  - Residual reactions still produce 5-7% of full heating power






Case Study
# Three Mile Island Nuclear Accident

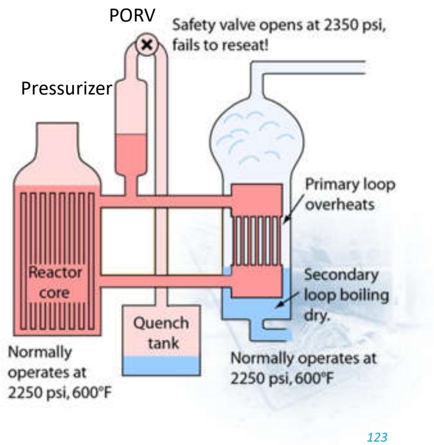
- **Pilot-Operated Relief Valve** tries to close when **pressure** drops below 2300 psi
- But it failed to reclose due to mechanical malfunction
- However, it closes enough to trip the **indicator** in the control room
- **Operators** think it is closed






Case Study
# Three Mile Island Nuclear Accident

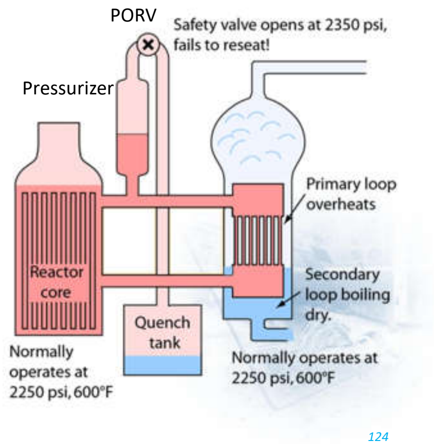
- As **PORV** keeps open, **reactor coolant** pressure drops below 1600 psi
- Low pressure triggered **Emergency Core Cooling System (ECCS)** starts automatically to avoid uncovered **core**
- ECCS floods the core with high pressure water





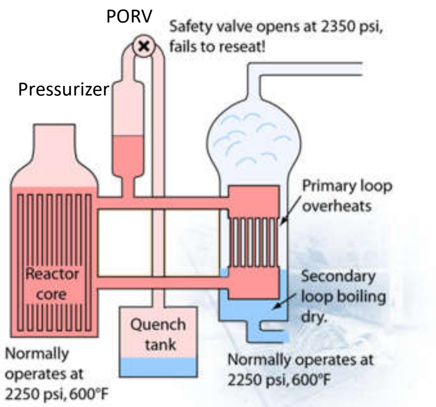

Case Study
# Three Mile Island Nuclear Accident

- Given
  - **Pressurizer Level** increases
  - **Pressurizer Pressure** fluctuates
  - **PORV** close
- **Operators** never think it is a loss-of-coolant accident
  - Since In training, **Loss of Coolant** = Low Pressure + Low Water Level
- This is true only in huge leakage



Case Study
# Three Mile Island Nuclear Accident

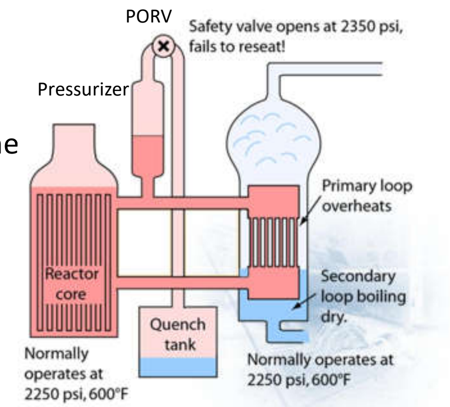
- **Small leakage is different**
  - **Pressure** dropped
  - **Water** in the reactor began to boil
  - **Steam** expanded and pushed water into the **pressurizer**
  - **Pressurizer level** went UP






Case Study
# Three Mile Island Nuclear Accident

- Operators worry that too much water could damage equipment
- Close **Emergency Core Cooling System**
- **Cooling** became insufficient to cover the **fuel**
  - Fuel rods were exposed to high-temperature steam
- Severe fuel damage
  Partial core meltdown occurred






Case Study
# Three Mile Island Nuclear Accident

| Time | Event |
|---|---|
| **0** | Auxiliary pump shuts down due to improperly closed valve in demineralizer. |
| **2 sec** | Pressure rises to 2255 psi, opens relief valve. It fails to close. |
| **8 sec** | Sensing high pressure, reactor "scrams", dropping all control rods |
| **9 sec** | Fission reaction stops, but still produce heat |
| **14 sec** | Operator notes that emergency feedwater pumps are on |
| **105 secs** | Steam generator (secondary loop) boils dry |
| **120 secs** | Emergency core cooling system (ECCS) automatically turns on when pressure drops below 1600 psi |
| **150 secs** | Operators shut down the ECCS<br>By this time the operators were dealing with about 100 alarms!! |



Case Study: Three Mile Island Nuclear Accident
# HMI Failure

- **Misleading Display**
  - PORV failed mechanically
  - Valve became stuck open
  - Cooling water continued to escape
  - Control room display showed:
    **"Close command sent to PORV"**

Case Study: Three Mile Island Nuclear Accident

# HMI Failure

- **“Firehose Effect” (Data Overload)**
  - Pressure anomalies
  - Temperature anomalies
  - Water level anomalies
  - No grouping, No prioritization, No causal structure



Case Study: Three Mile Island Nuclear Accident

# HMI Failure

- **Fail in Level 2 SA: Comprehension**
  - Operators believed:
    - Reactor had too much water
  - Manually shut down the pump to reduce cooling
  - Incorrect mental model



Case Study: Three Mile Island Nuclear Accident

# HMI Failure

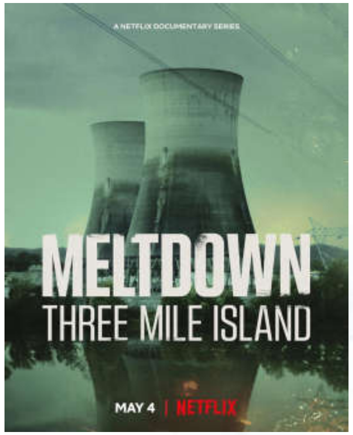
- **Swiss Cheese Model**
  - Layer 1- **Hardware:** PORV mechanical failure
  - Layer 2- **HMI:** Display showed commands, not reality
  - Layer 3- **Alarms:** Firehose effect, no prioritization
  - Layer 4- **Procedures & Training:** Assumed valve would close and no guidance for this failure mode
  - Layer 5- **Human:** High stress, high workload



Case Study: Three Mile Island Nuclear Accident

# Summary

- A system can have all the right data, and still fail catastrophically because the interface did not support human understanding.




但这件事却发生在三哩岛核电站

# Motor Feedback Loop

- **Design goal:**
  Provide **immediate and continuous visual or haptic feedback** to support closed-loop control and improve accuracy.
- **Closed-loop control:**
  The user moves, **perceives continuous feedback** (e.g., cursor motion), and **adjusts the movement in real time**
  *(slower, but more accurate)*
- **Open-loop control:**
  A **rapid, pre-planned (ballistic) movement** executed with little or no feedback during execution
  *(fast, but prone to overshooting)*



# Speed-Accuracy Trade-off

- As movement speed increases, accuracy decreases
  - Faster actions → more errors
  - Slower actions → higher precision
- **Cognitive Perspective**
  - Rushed decisions increase mistakes
  - Under time pressure, attention narrows
  - Reaction quality decreases
- **Motor Control Perspective**
  - Fast movement = less time for feedback correction
  - Slower movement = more closed-loop control



# Speed-Accuracy Trade-off

- **Design Implication**
  - When speed increases, design must protect accuracy
  - **Safety-Critical Systems**
    - Make critical targets large
    - Use clear feedback
    - Reduce unnecessary complexity
  - **Everyday UI**
    - Avoid placing small buttons near dangerous actions
    - Use confirmation for irreversible actions

# Signal Detection Theory (SDT)

- Design Goal
  Minimize Miss (safety risk) +
  False Alarm (causes "Alarm Fatigue")

| | User Detects | User Fails to Detect |
|---|---|---|
| Signal Present | Hit | Miss |
| No Signal | False Alarm | Correct Rejection |