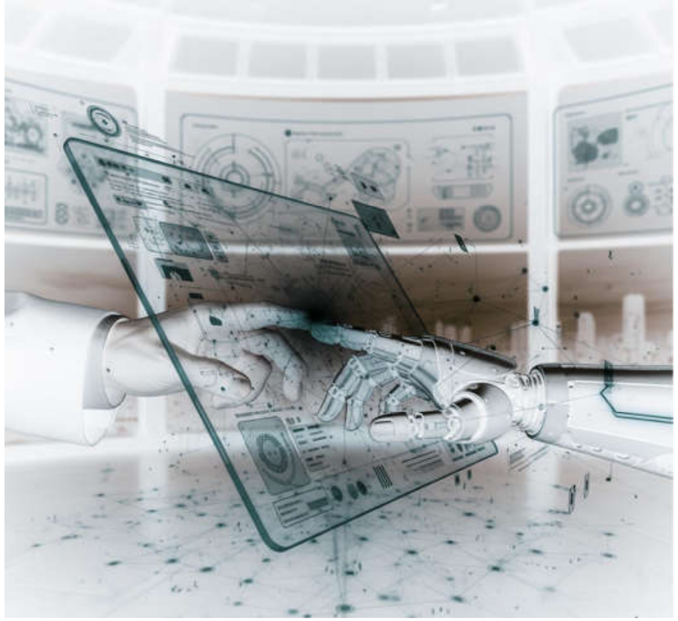

Human-Machine Interaction

HMI Introduction

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More Powerful & Autonomous

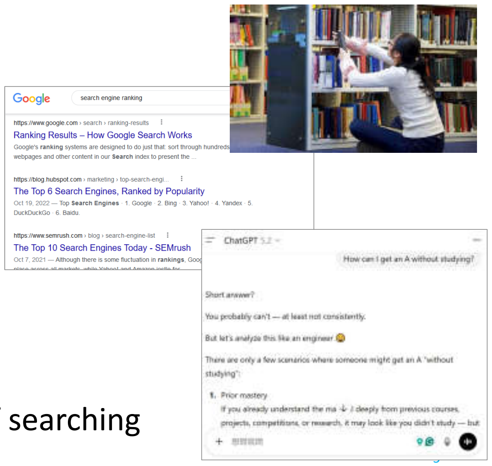
Application: Photography

- **Manual Camera**
  - User sets focus, exposure, shutter
  - Machine only captures light
- **Auto-Focus / Auto-Exposure**
  - Detects face; Adjusts brightness automatically
  - Human: supervises and corrects
- **Computational Photography**
  - Scene understanding (food, night, portrait); Multi-frame AI enhancement; Auto object removal / enhancement

More Powerful & Autonomous

Application: Information Search

- **Library Search**
  - Find books manually
- **Search Engine**
  - Returns ranked results
  - User filters information
- **Answer Engine / AI Assistant**
  - Provides direct answers
  - Summarizes sources
  - User evaluates truth instead of searching



More Powerful & Autonomous

Application: Medical Diagnosis

- **Measurement Device**
  - Doctor interprets data
  - Machine provides data only
- **Decision Support System**
  - Flags abnormal patterns; Suggests possible diagnosis
  - Human evaluates suggestions
- **AI Clinical Prediction**
  - Predicts deterioration risk; Recommends treatment priority
  - Human supervises AI judgment

Why HMI?

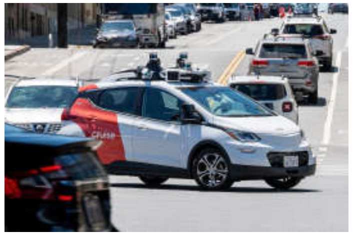
More Powerful & Autonomous

- Modern machines no longer just execute commands
- **Sense → Decide → Act**
  - Faster than human reaction time
  - Operate continuously without fatigue
  - Make decisions in complex environments
  - Increasing autonomy (human supervises instead of controls)
- Humans are shifting from *operator → supervisor*

Why HMI? More Powerful & Autonomous

Example: Autonomous Driving

- Understands lanes, vehicles, pedestrians
- Predicts motion of other agents
- Makes real-time driving decisions

Why HMI? More Powerful & Autonomous

Example: Surgical Robot

- More precise than a human hand
- Removes hand shaking (tremor filtering)
- Large hand movement becomes very small tool movement
- Makes minimally invasive surgery possible


Why HMI?

Technology Paradox

Example: Smart Infusion Pumps

- Modern hospitals use **smart infusion pumps** to automatically control medication delivery
  - Include drug libraries including dosage limits for a drug
  - Alarm triggered when violation to prevent nurses from giving wrong drug dosage
- **Look a great idea?!?**

Example: Smart Infusion Pumps

- In reality, a hospital treats very different patients: child, adult, elder, kidney failure, emergency cases, unusual body weight
- Doctors intentionally prescribe doses outside the standard range
- This looks like an error to the machine
  - Alarm triggered
  - Nurses have to turn off the alarm before treatment

Example: Smart Infusion Pumps

- **Pattern**
  - Nurse selects drug from list
  - System alarm triggers (limit exceeded)
  - Nurse believes dosage is correct
  - Nurse overrides safety warning
  - Patient receives dangerous dose
- Why do nurses ignore the warning?
  - Because the alerts occur too frequently

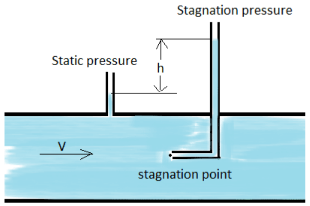
Example: Air France Flight 447

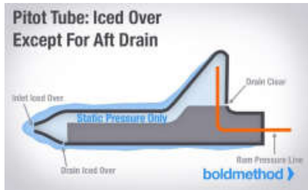
- In 2009
  Aircraft: Airbus A330
  Route: Rio → Paris
  Weather: High altitude thunderstorm
- Consequences
  - **228 fatalities**
  - No mechanical failure found
  - Highly trained professional pilots

Why HMI? Technology Paradox

Example: Air France Flight 447

- Airspeed is measured by using **pitot tubes** (pressure sensors)
- In high altitude icing, the pitot tubes froze
  - Speed readings became unreliable
- **Other than this**
  the whole airplane flies normally





Why HMI? Technology Paradox

Example: Air France Flight 447

- Airbus Autopilot Logic:
  If airspeed data unreliable → autopilot disconnect
- Aircraft switched: **Normal State → Alternate State**
  - Alternate State:
    - Pilot must manually fly
    - Many protections removed

Why HMI? Technology Paradox

Example: Air France Flight 447

- Within 5 seconds,
  In night storm, no outside visibility,
  Pilots got:
  - Speed indications disagree
  - Autopilot disconnect alarm
  - Flight control behavior changed
  - Multiple warning sounds
- **What should you do?**

A Side Node
Captain Sully safely landed US Airways Flight 1549 on the Hudson River, saving all 155 people on board.

Why HMI? Technology Paradox

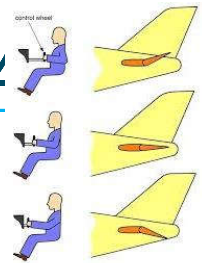
Example: Air France Flight 447

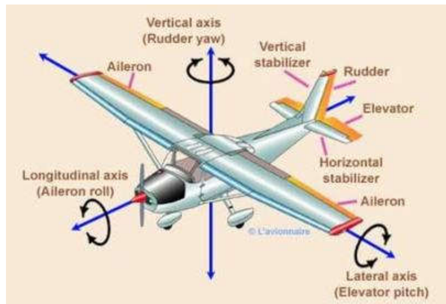
- The pilot pulled the stick UP
- Nose up → Climbing
- **Why?**

- Uncertain + Alarm = Danger

= Climb instinct

= Gain more control margin

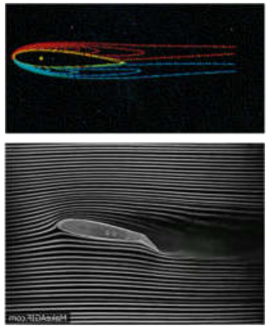




Why HMI? Technology Paradox

Example: Air France Flight 447

- Keep pulling up, What happens?
- A Stall occurs



Why HMI? Technology Paradox

Example: Air France Flight 447

- There is **stall warning** in the pre-stall situation
- But the stall warning sounded, then stopped, then sounded again, …
- **Why? What does it mean?**
- Stall detection depended on airspeed data
  - Pitot tubes does not work normally
  - Stall detection becomes unreliable

Why HMI? Technology Paradox

Example: Air France Flight 447

- Pilots did not recognize that the aircraft was actually stalled in this complicated situations
  - Unstable warning
  - Many warnings
  - Short Decision Time
- Pilots kept pulling up to avoid the aircraft descending too fast

Why HMI? Technology Paradox

Example: Air France Flight 447

- Consequence
  - Aircraft: fully stalled
  - Nose: pointed upward
  - Falling: 10,000 ft per minute
    - Nearly free fall speed 10,560 ft per minute
  - 228 fatalities

Why HMI?

Technology Paradox

- **Expectation:**
  Better technology →
  Fewer errors →
  Safer systems →
  Better outcomes
- **Reality:**
  Better technology ≠
  Better outcomes

- **Why?**

Why HMI? Technology Paradox

Advanced Machines Perform badly?

- Modern systems are powerful and intelligent
- Users are trained professionals
- But serious mistakes still occur
- Why?

- Performance depends on
  the human–machine system, not either alone

Why HMI? Technology Paradox: Advanced Machines Perform badly?

Complexity vs Human Capacity

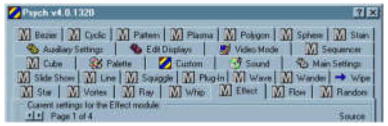
- Machine abilities increase exponentially
- Human abilities are fixed
  - E.g. memory, attention, reaction time

- When systems demand more cognition than humans can provide, errors occur
  - E.g. Able to ride a bicycle car ≠ Able to drive a car

Why HMI? Technology Paradox: Advanced Machines Perform badly?

Interfaces Designed for Machines

- Many interfaces mirror the system's internal implementation
  - Show how the system works
  - Not how the human thinks
- Users must translate rather than simply operate



Why HMI? Technology Paradox: Advanced Machines Perform badly?

Interfaces Designed for Machines

- Automated systems are more complex and contain internal modes/states
- As users cannot clearly see what the system is doing, cannot fully understand
- Uncertainty leads to incorrect actions

Why HMI? Technology Paradox: Advanced Machines Perform badly?

Interfaces Designed for Machines

- Automation change human roles
  - No longer actively controls the system
  - Mental engagement decreases
- **Sudden Handover**
  Control transfers at the worst moment
- **Over-Trust**
  Believing the system even when wrong

HMI?

Technology Paradox

- Advanced and intelligent systems are often:
  - Hard to operate
  - Misunderstood by users
- Changes the nature of failures, not frequency
  - Most failures are interaction failures, not hardware failures
  - Systems become technically safer but operationally riskier

Why HMI? Technology Paradox

Are Training/Rules Helpful?

- Can interaction failures solved by Training/Rules?
  - Humans are highly adaptable
  - Typical response after incidents:
    More training, manuals, procedures

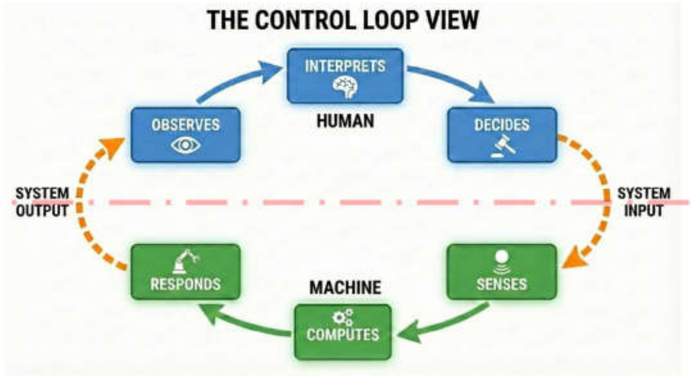
Why HMI? Technology Paradox

Are Training/Rules Helpful?

- **Treat Symptoms, not root causes**
  - Humans can compensate for poor design
    - The system appears functional but safety margins still small
- The issue is **not user competence**
  - Many accidents involve: experts, professionals, and trained operators

Human-Machine Interaction

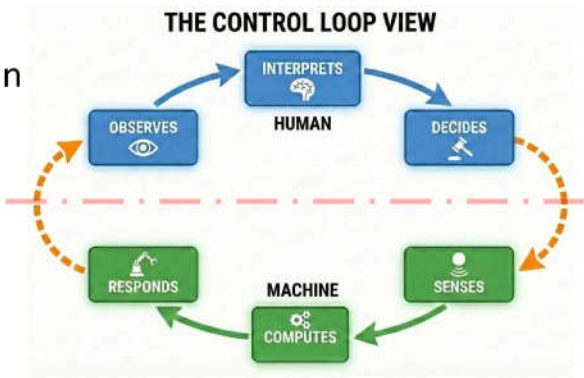
- **Traditional View**: Human operates the machine
- **Modern View**: Human is a component inside the control loop



Human-Machine Interaction

Human-Machine Interaction

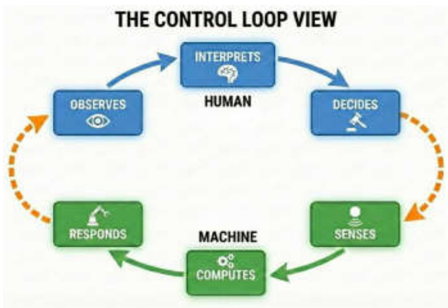
- Poor HMI breaks the control loop:
  - incorrect interpretation
  - delayed response
  - unexpected system behavior
- Failure occurs



Human-Machine Interaction

Perception, Decision, and Control

- Human interaction introduces
  - **Perception**
    Sense signals
  - **Understanding**
    Interpret as meaningful information
  - **Decision**
    Evaluates and chooses actions
  - **Control (Action)**
    Manipulates system behavior
- This process is similar to the machine



Variable Human Behavior

- Unlike machines,
  humans are not constant controllers
- Human response gain changes over time
  - Depends on:
    workload, fatigue, stress, trust, …
  - Parameters are dynamic

From Tools to Teammates

- Modern systems have intelligent
  - Sense, decide, and act
- No longer simple tools but
  teammates to humans
- Human and machine must be
  treated as one **integrated system**

New Requirements

- Engineering traditionally optimizes:
  - accuracy
  - speed
  - efficiency
  - reliability
- Intelligent systems depend on:
  - understanding
  - attention
  - trust
  - interpretation

Human-Machine Interaction

- **Traditional Engineering Focus**
  Design the machine to work correctly
- **HMI Engineering Focus**
  Design the human-machine system to work correctly
- **Human-Machine Interaction (HMI)**
  Design a system which
  humans and machines form a stable control loop

Beyond Software Interfaces

- NOT making interfaces pretty or convenient
- NOT limited to screens and buttons
  - It involves physical systems
  - Actions have physical consequences
- HMI affects safety in the real world

Interface vs Interaction

- **Interface**
  The visible input/output elements (buttons, screens, alarms)
- **Interaction**
  The dynamic behavior between human and machine over time

- **Good interface does not guarantee good interaction**

Interdisciplinary

- The goal is to design working human-machine systems
  - Not to study humans or design machine alone
- Draws knowledge from:
  - **Psychology** (human cognition)
  - **Biology** (human perception)
  - **Control Theory** (feedback loops)
  - **Computer Science** (automation)
  - **Engineering** (system behavior)

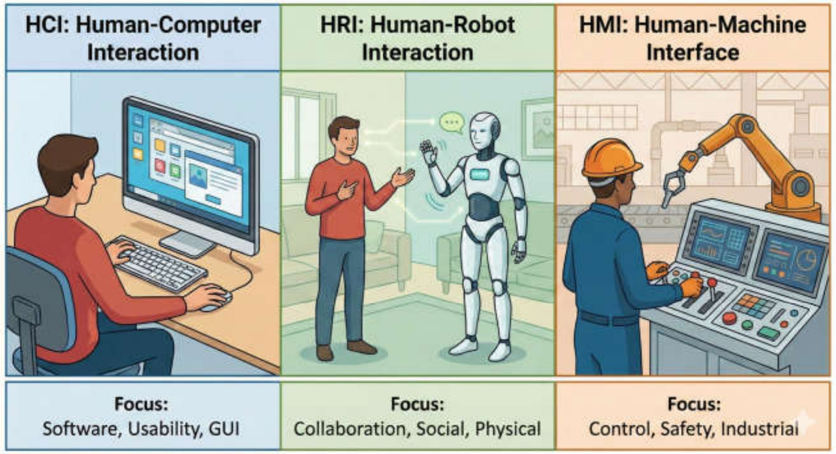
Psychology, Biology } **Human**

Control Theory, Computer Science, Engineering } **Machine**

HCI vs HRI vs HMI

- **Human–Computer Interaction (HCI)**
  - Between: humans and **software systems**
  - Focus: information manipulation and usability
  - E.g. Navigating a mobile app
- **Human–Robot Interaction (HRI)**
  - Between : humans and **embodied robots**
  - Focus: behavior, motion, cooperation, safety
  - E.g. Interacting with a Robot Vacuum Cleaners
- **Human–Machine Interaction (HMI)**
  - Between : humans and **engineered systems**
  - Focus: control, feedback, and joint task execution
  - E.g. the control panel of a nuclear power plant

HCI vs HRI vs HMI



HCI vs HRI vs HMI

Key Differences

Aspect	HCI	HRI	HMI
Embodiment	Virtual	Physical robot	Any machine
Physical consequences	Usually indirect	Direct physical	Often safety-critical
Autonomy	Low–medium	Medium–high	Wide spectrum
Main problem	Usability	Cooperation	System stability & safety

HCI vs HRI vs HMI

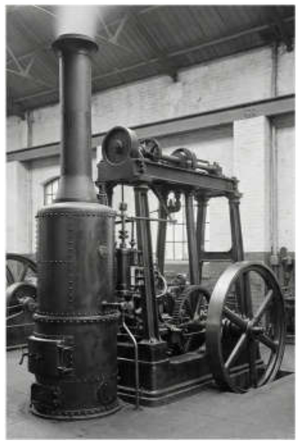
Relationship

- HCI focuses on information interaction
  HRI focuses on embodied cooperation
- But **modern engineered systems** include:
  - Software interfaces
  - Physical devices
  - Automation behavior
- **HMI studies the whole operational system**
  - HCI ⊂ HMI and HRI ⊂ HMI

Brief HMI History

1850-1940: Mechanical Era

- Direct physical coupling
  - E.g. Levers, pulleys, and gears
- Human "felt" the machine
  - Energy and Information were the same.
- Physical strength was a requirement
- Feedback was raw (heat, vibration, noise)



Brief HMI History

1940-1970: Electromechanical Era

- Remote control through electricity
  - Gauges, knobs, and lightbulbs
- As machines got complex, cockpits contains hundreds of single-purpose gauges
  - Cognitive Load is very High
  - Operators had to scan dozens of indicators to understand system state

Brief HMI History

1980-2000: Digital Era

- Screens (CRTs & LCDs) replaced physical gauges
- Information became Layered
  Only see what is on the current screen
  - **Pros**: Reduced clutter by showing only relevant information
  - **Risk**: Losing the big picture (may not know what is going on)

Brief HMI History

2000-Present: Automation Era

- Machine intelligence
  the system now makes its own decisions
- Human becomes a supervisor rather than a direct operator
- Interaction moves from physical manipulation to abstract, logic-driven control.

Brief HMI History

Evolution with Automation

- Systems became automated:
  - **Old interaction**: Muscle effort and perception
  - **Modern interaction**: Interpretation and decision-making
- Interaction became cognitive rather than physical
  - **Operators**: read symbols, understand modes, and predict behavior

Brief HMI History

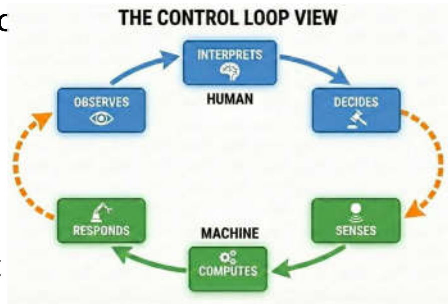
Why HMI Is More Critical Today

- Lessons Learned from History
  Major incidents repeatedly showed:
  - machines worked correctly
  - operators were trained
  - **misunderstanding caused failure**

- Technology advanced faster than interaction design

Course Syllabus

- **Ch02** Human Factor
- **Ch03** User Centered Design Metho
- **Ch04** Interaction Modalities and Technologies
- **Ch05** Human-in-the-Loop Collaboration Mechanisms
- **Ch06** Evaluation, Safety, and Trust HMI Systems
- **Ch07** Application



Course Syllabus

Human Factor

- Machines are precise and deterministic
  Humans are adaptive but limited
- Aim to understand the **capabilities and limitations of the human operator**
  - Human Capability & Limitations
  - Human State & Workload
  - Human Failure in Intelligent Systems
  - Real Accident Case Studies

Course Syllabus

User Centered Design Method

- Engineers often design for the system
  Instead of designing for the human
- Systematically translate **human needs → engineering decisions**
  - Understanding Users
  - From Data to Requirements
  - Modeling Users
  - Prototyping and Iteration

Course Syllabus

Interaction Modalities

- Interaction is not only through buttons and screens
- Humans communicate using multiple senses and actions
  - Visual and auditory interaction
  - Gesture and motion interaction
  - Haptic and tactile interaction
  - Physiological-signal-driven interaction

Course Syllabus

Human-in-the-Loop Collaboration

- Robots are no longer isolated machines
  They now share space and tasks with humans
- Not only making robots smarter but making autonomy compatible with human safety and understanding
  - Autonomy and Human Roles
  - Shared Control
  - Human-Aware Planning
  - Collaborative Robots (Cobots)

Course Syllabus

Evaluation, Safety, and Trust

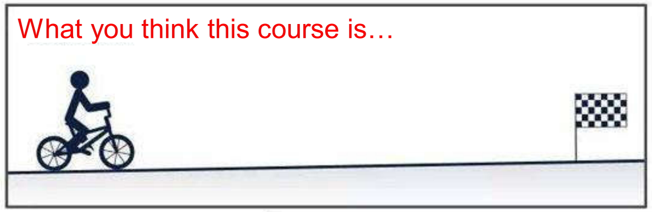
- Engineering does not end at implementation
  It ends when interaction is reliable
  - Evaluating Interaction
  - Designing for Failure
  - Safety Principles
  - Trust and Responsibility

Course Syllabus

Application

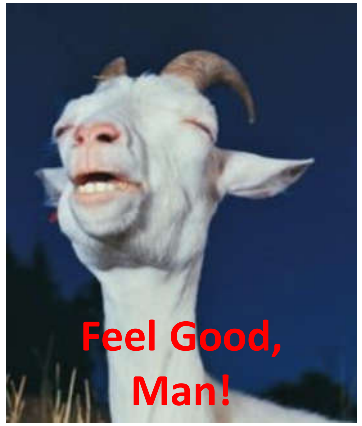
- HMI principles are only valuable when they work in real environments
- Different domains create different interaction challenges
- Introduce real life applications

About This Course



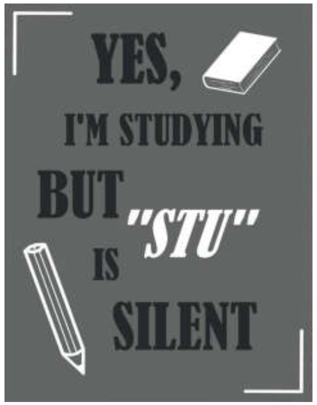
About This Course

- **Traditional technical courses**
  - Explain how systems work
  - Contain complicated algorithms and complex formulas
  - Make you feel professional
- Unfortunately, this course is nothing similar to these



About This Course

- This is an **engineering course**
  - Look simple and easy to understand
  - Sometimes it may even feel obvious
    - *like saying "your mother is a woman"*
  - Sometimes it may be too detailed
    - *like a boring user manual*



About This Course

- But:
  - Real value appears when you apply it
  - Simple principles prevent serious problems in practice
  - Simple ideas, powerful engineering impact
- Work hard
  Do not regret it when you lose this learning opportunity

About This Course

- What is the problem?

About This Course

- Why are there so many rules?

keep window shades open during takeoff and landing

do not inflate the life vest inside the cabin

About This Course

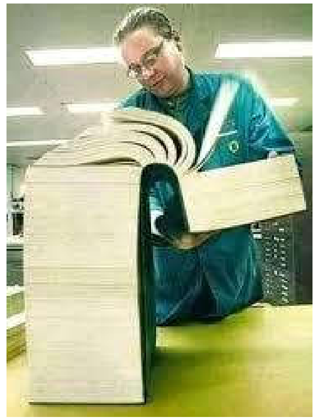
- Those procedures / rules come from lessons learned through painful experience
- This is similar to what we will learn in this course
  - When you first see the rules, they may look simple
  - But if you do not aware of them, your designed system may cause serious mistakes

- Goal: **not only knowledge**, but **mindset**

About This Course

- This course is about Human
- Understanding human is often a weakness of science students
  - Good at understanding machines, but not human

- You are human.
  Do you think you understand humans?



Book of How to understand human (volume 1)

About This Course

- What does she mean?

About This Course

- How to communicate clearly
  - How to express your intent
  - How to listen and understand others
- How to collaborate effectively
- How to build trust

- These are also concerns in human–machine systems

About This Course

- Hope you will find a way to appreciate this course
  - May be not now, but some days when you grow up
- Its value may not appear immediately, but it will grow with experience

Me after I finally understand it…

About This Course

- Reduce one-way passive learning
- Less lecture, more interaction.
  - Discussion
  - Short Sharing
  - Group Project
- Please speak more than I do