# RISK AND PLANNING FOR MISTAKES II

Eunsuk Kang

Required reading: Hulten, Geoff. "Building Intelligent Systems: A Guide to Machine Learning Engineering." (2018), Chapters 6–7 (Why creating IE is hard, balancing IE) and 24 (Dealing with mistakes)

# LEARNING GOALS:

- Evaluate the risks of mistakes from AI components using the fault tree analysis (FTA)
- Design strategies for mitigating the risks of failures due to AI mistakes

# RISK ANALYSIS

# WHAT IS RISK ANALYSIS?

# WHAT IS RISK ANALYSIS?

- What can possibly go wrong in my system, and what are potential impacts on system requirements?

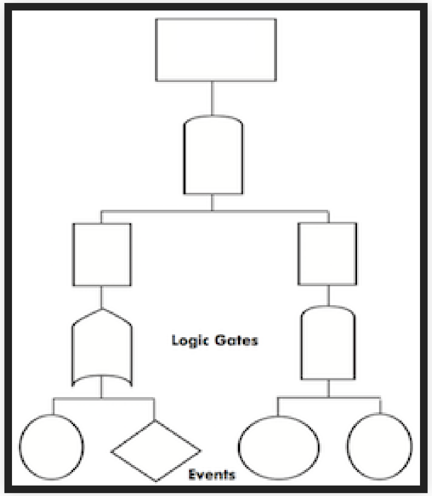
# WHAT IS RISK ANALYSIS?

- What can possibly go wrong in my system, and what are potential impacts on system requirements?
- Risk = Likelihood * Impact

# WHAT IS RISK ANALYSIS?

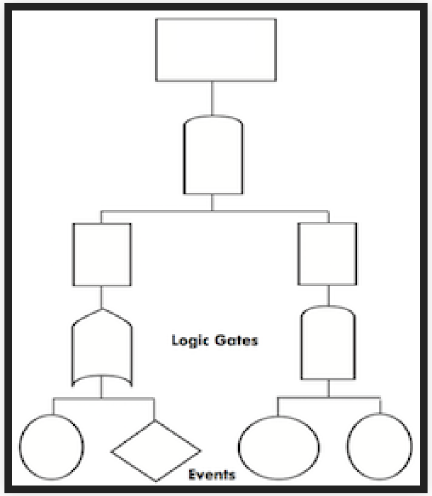
- What can possibly go wrong in my system, and what are potential impacts on system requirements?
- Risk = Likelihood * Impact
- A number of methods:
    - Failure mode & effects analysis (FMEA)
    - Hazard analysis
    - Why-because analysis
    - Fault tree analysis (FTA) <= Today's focus!
    - ...

# FAULT TREE ANALYSIS (FTA)



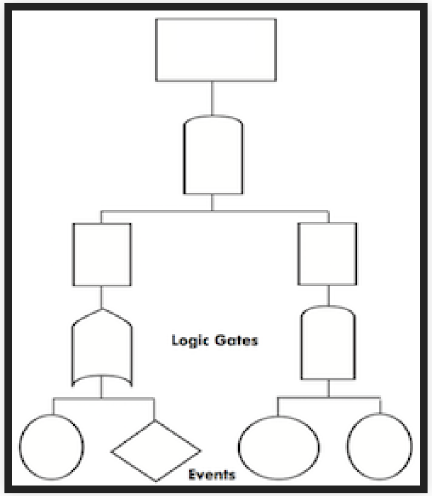
# FAULT TREE ANALYSIS (FTA)

- Fault tree: A top-down diagram that displays the relationships between a system failure (i.e., requirement violation) and its potential causes.
    - Identify sequences of events that result in a failure
    - Prioritize the contributors leading to the failure
    - Inform decisions about how to (re-)design the system
    - Investigate an accident & identify the root cause



# FAULT TREE ANALYSIS (FTA)

- Fault tree: A top-down diagram that displays the relationships between a system failure (i.e., requirement violation) and its potential causes.
  - Identify sequences of events that result in a failure
  - Prioritize the contributors leading to the failure
  - Inform decisions about how to (re-)design the system
  - Investigate an accident & identify the root cause
- Often used for safety & reliability, but can also be used for other types of requirement (e.g., poor performance, security attacks...)



# FAULT TREE ANALYSIS & AI

- Increaseingly used in automotive, aeronautics, industrial control systems, etc.,

# FAULT TREE ANALYSIS & AI

- Increaseingly used in automotive, aeronautics, industrial control systems, etc.,
- AI is just one part of the system

# FAULT TREE ANALYSIS & AI

- Increaseingly used in automotive, aeronautics, industrial control systems, etc.,
- AI is just one part of the system
- AI will EVENTUALLY make mistakes
    - Ouput wrong predictions/values
    - Fail to adapt to changing environment
    - Confuse users, etc.,

# FAULT TREE ANALYSIS & AI

- Increaseingly used in automotive, aeronautics, industrial control systems, etc.,
- AI is just one part of the system
- AI will EVENTUALLY make mistakes
    - Ouput wrong predictions/values
    - Fail to adapt to changing environment
    - Confuse users, etc.,
- How do mistakes made by AI contribute to system failures? How do we ensure their mistakes do not result in a catastrophe?

# FAULT TREES:: BASIC BUILDING BLOCKS

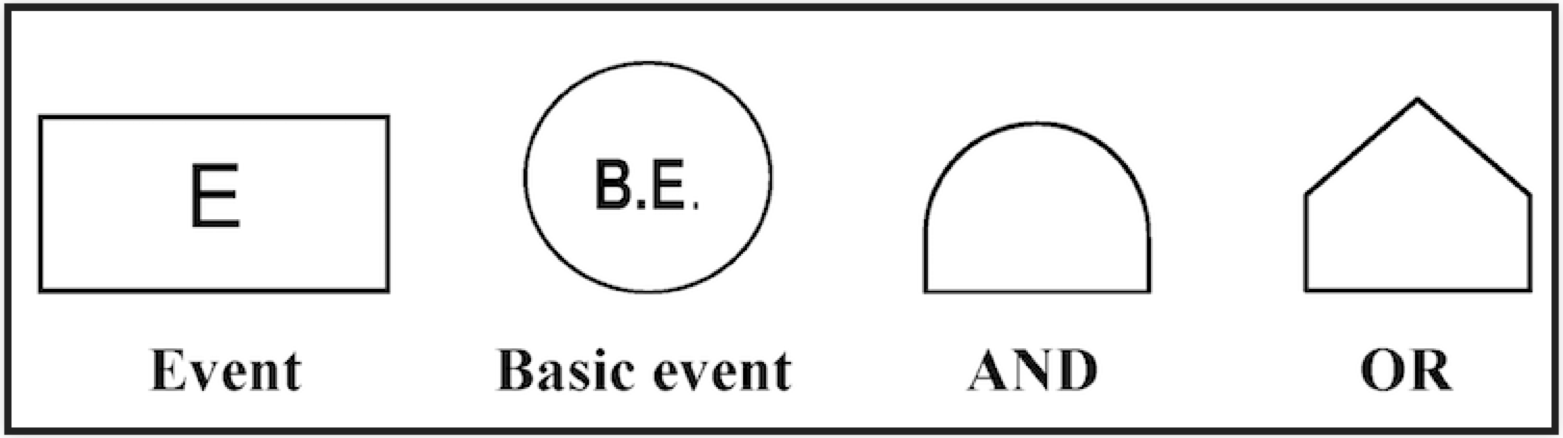
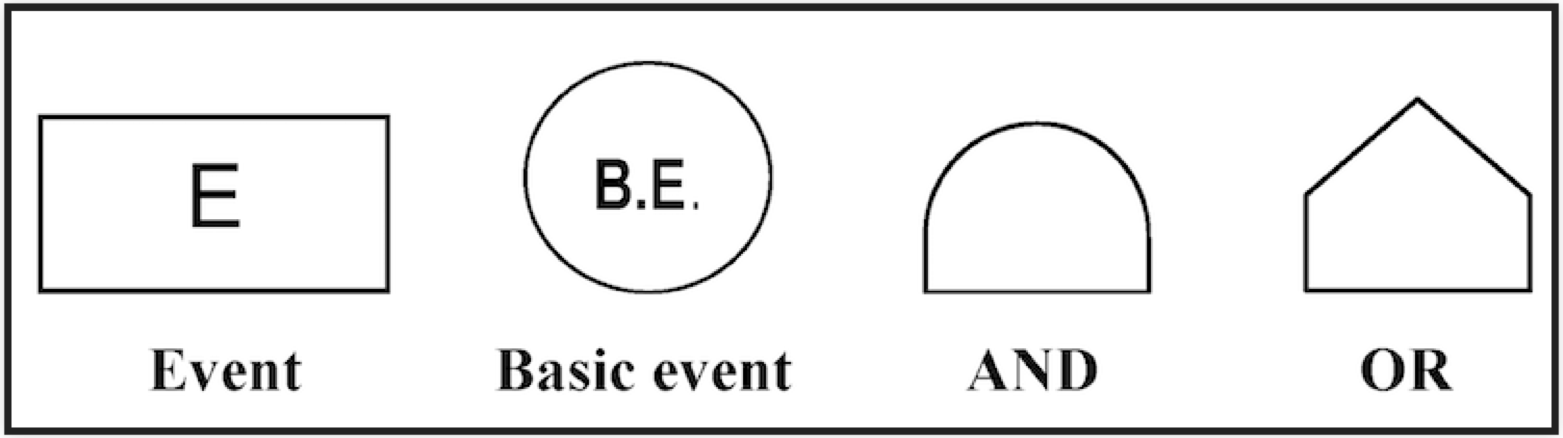



Figure from *Fault Tree Analysis and Reliability Block Diagram* (2016), Jaroslav Menčík.

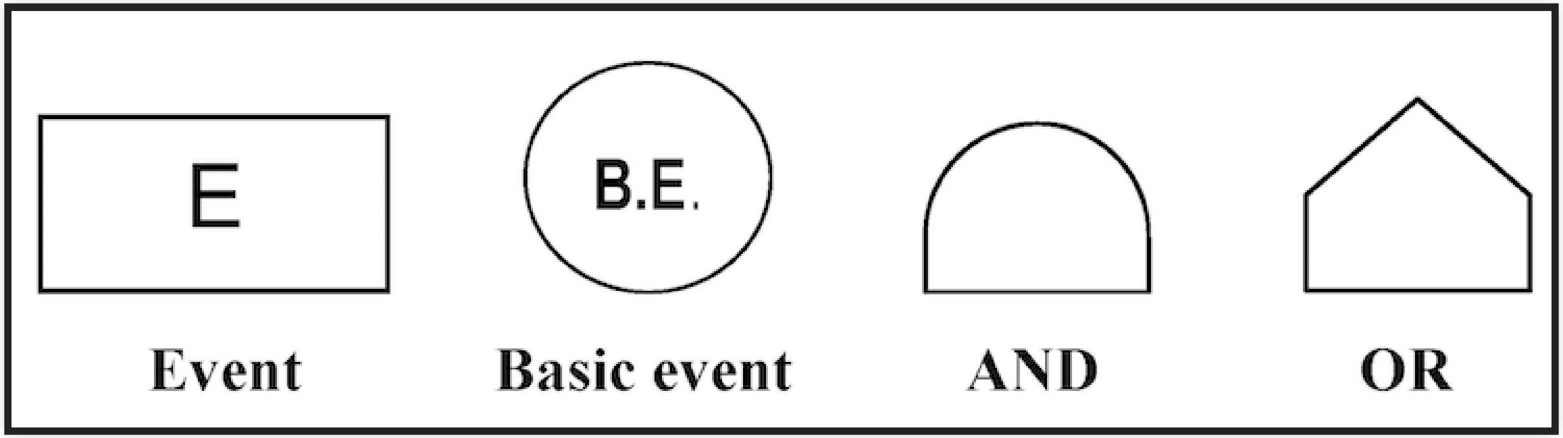
# FAULT TREES:: BASIC BUILDING BLOCKS




- Event: An occurrence of a fault or an undesirable action
  - (Intermediate) Event: Explained in terms of other events
  - Basic Event: No further development or breakdown; leafs of the tree

Figure from *Fault Tree Analysis and Reliability Block Diagram* (2016), Jaroslav Menčík.

# FAULT TREES:: BASIC BUILDING BLOCKS




- Event: An occurrence of a fault or an undesirable action
  - (Intermediate) Event: Explained in terms of other events
  - Basic Event: No further development or breakdown; leafs of the tree
- Gate: Logical relationship between an event & its immedicate subevents
  - AND: All of the sub-events must take place
  - OR: Any one of the sub-events may result in the parent event

Figure from *Fault Tree Analysis and Reliability Block Diagram* (2016), Jaroslav Menčík.

# FAULT TREE EXAMPLE

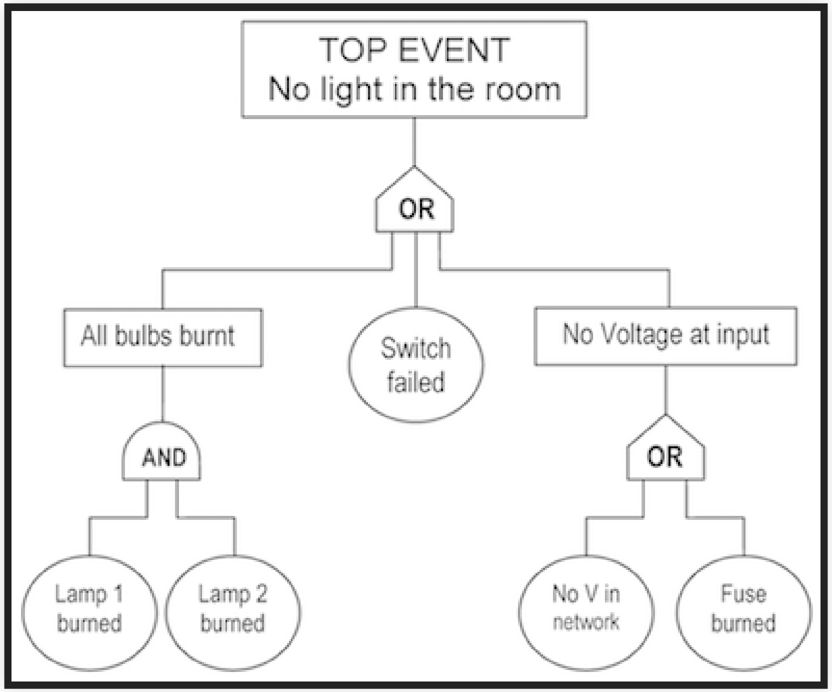
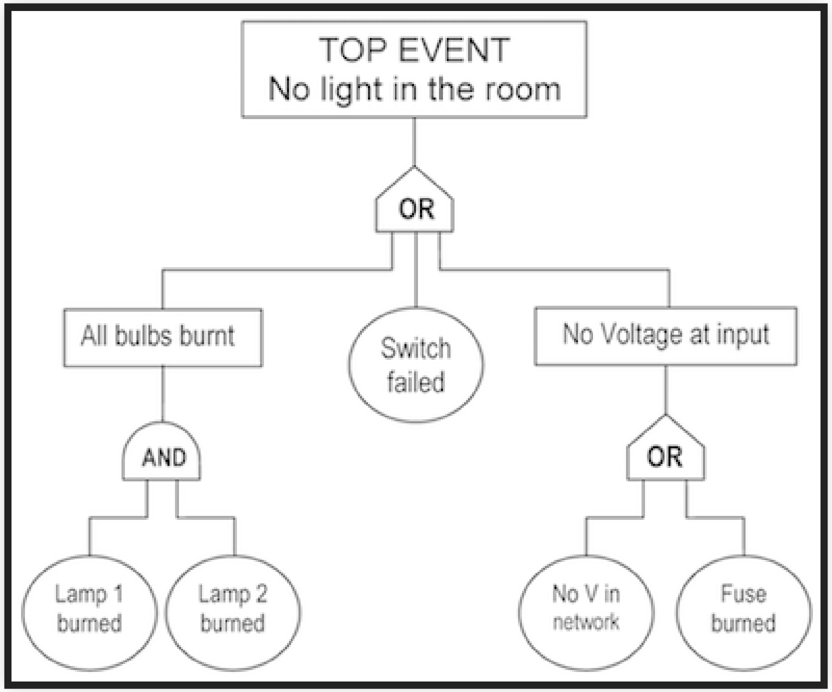



Figure from *Fault Tree Analysis and Reliability Block Diagram* (2016), Jaroslav Menčík.

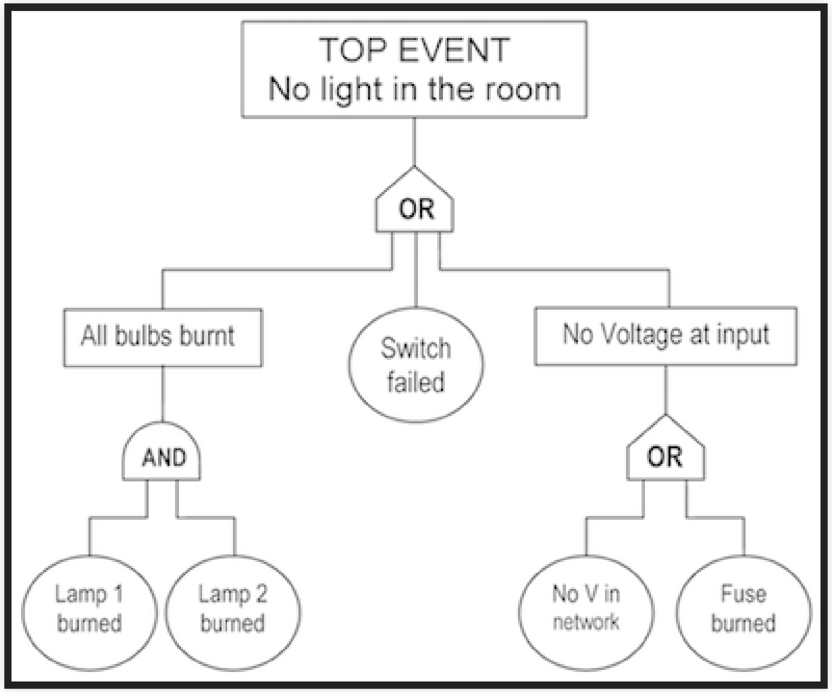
# FAULT TREE EXAMPLE




- Every tree begins with a TOP event (typically a violation of a requirement)

Figure from *Fault Tree Analysis and Reliability Block Diagram* (2016), Jaroslav Menčík.

# FAULT TREE EXAMPLE



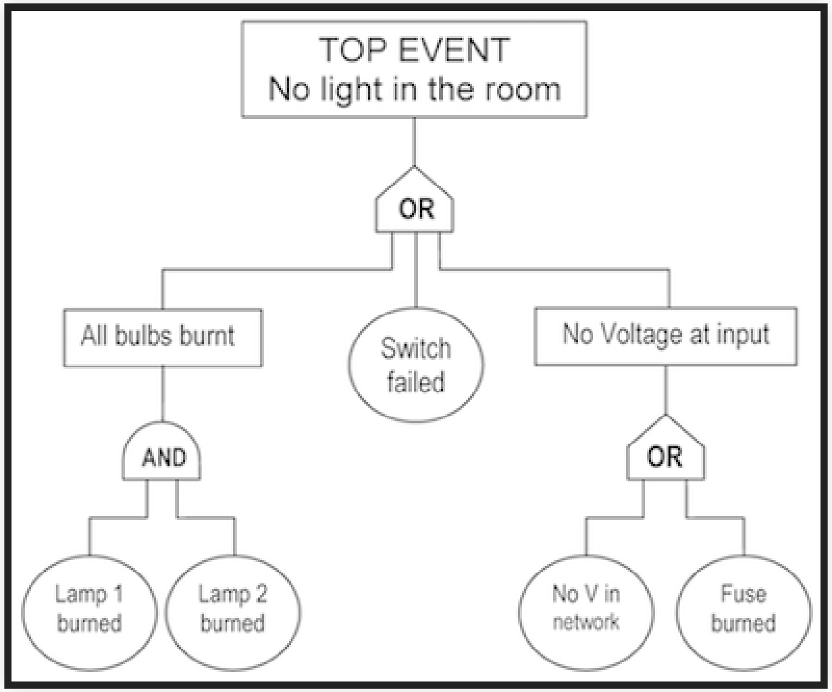

- Every tree begins with a TOP event (typically a violation of a requirement)
- Every branch of the tree must terminate with a basic event

Figure from *Fault Tree Analysis and Reliability Block Diagram* (2016), Jaroslav Menčík.

# ANALYSIS

- What can we do with fault trees?
    - Qualitative analysis: Determine potential root causes of a failiure through *minimal cut set analysis*
    - Quantitative analysis: Compute the probablity of a failure

# MINIMAL CUT SET ANALYSIS




- Cut set: A set of basic events whose simultaneous occurrence is sufficient to guarantee that the TOP event occurs.
- *Minimal* cut set: A cut set from which a smaller cut set can be obtained by removing a basic event.
- Q. What are minimal cut sets in the above tree?

# FAILURE PROBABILITY ANALYSIS

# FAILURE PROBABILITY ANALYSIS

- To compute the probability of the top event:
    - Assign probabilities to basic events (based on domain knowledge)
    - Apply probability theory to compute prob. of intermediate events through AND & OR gates
    - (Alternatively, as sum of prob. of minimal cut sets)

# FAILURE PROBABILITY ANALYSIS

- To compute the probability of the top event:
  - Assign probabilities to basic events (based on domain knowledge)
  - Apply probability theory to compute prob. of intermediate events through AND & OR gates
  - (Alternatively, as sum of prob. of minimal cut sets)
- In this class, we won't ask you to do this.
  - Why is this especially challenging for software?

# FTA PROCESS

# FTA PROCESS

1. Specify the system structure
    - Environment entities & machine components
    - Assumptions (ENV) & specifications (SPEC)

# FTA PROCESS

1. Specify the system structure
    - Environment entities & machine components
    - Assumptions (ENV) & specifications (SPEC)
2. Identify the top event as a violation of REQ

# FTA PROCESS

1. Specify the system structure
    - Environment entities & machine components
    - Assumptions (ENV) & specifications (SPEC)
2. Identify the top event as a violation of REQ
3. Construct the fault tree
    - Intermediate events can be derived from violation of SPEC/ENV

# FTA PROCESS

1. Specify the system structure
    - Environment entities & machine components
    - Assumptions (ENV) & specifications (SPEC)
2. Identify the top event as a violation of REQ
3. Construct the fault tree
    - Intermediate events can be derived from violation of SPEC/ENV
4. Analyze the tree
    - Identify all possible minimal cut sets

# FTA PROCESS

1. Specify the system structure
    - Environment entities & machine components
    - Assumptions (ENV) & specifications (SPEC)
2. Identify the top event as a violation of REQ
3. Construct the fault tree
    - Intermediate events can be derived from violation of SPEC/ENV
4. Analyze the tree
    - Identify all possible minimal cut sets
5. Consider design modifications to eliminate certain cut sets

# FTA PROCESS

1. Specify the system structure
    - Environment entities & machine components
    - Assumptions (ENV) & specifications (SPEC)
2. Identify the top event as a violation of REQ
3. Construct the fault tree
    - Intermediate events can be derived from violation of SPEC/ENV
4. Analyze the tree
    - Identify all possible minimal cut sets
5. Consider design modifications to eliminate certain cut sets
6. Repeat

# EXAMPLE: FTA FOR LANE ASSIST


- REQ: The vehicle must be prevented from veering off the lane.
- ENV: Sensors are providing accurate information about the lane; driver responses when given warning; steering wheel is functional
- SPEC: Lane detection accurately identifies lane markings in image; the controller generates steering commands to keep the vehicle within lane

# BREAKOUT: FTA FOR LANE ASSIST

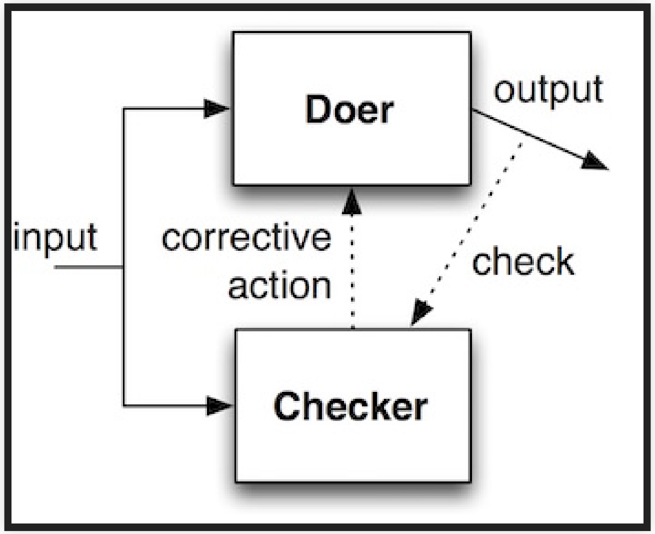
Draw a fault tree for the lane assist system with the top event as “Vehicle fails to stay within lane”

# MITIGATION STRATEGIES

# ELEMENTS OF FAULT-TOLERANT DESIGN

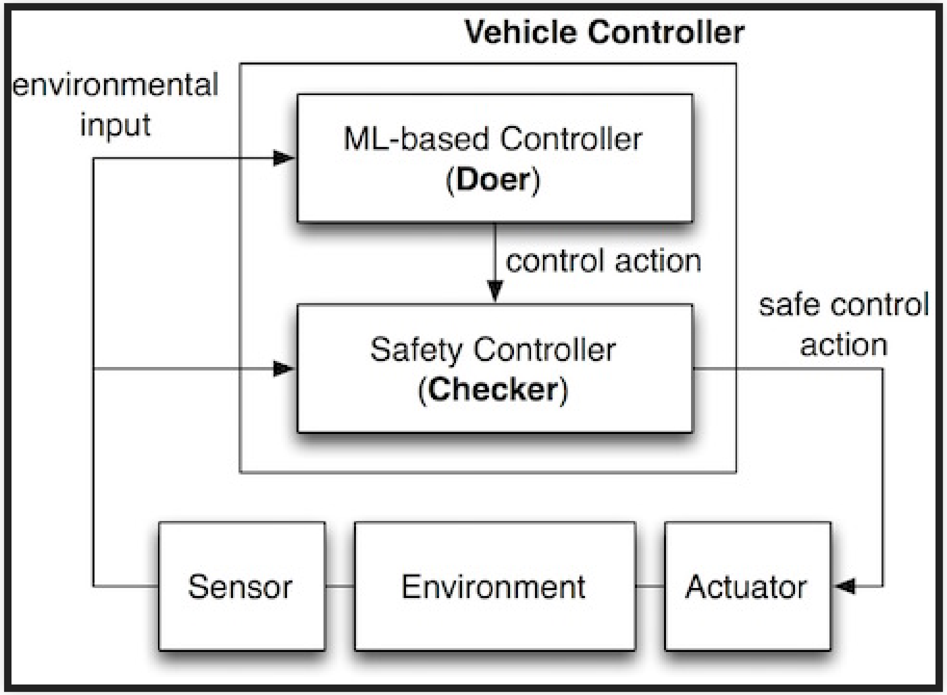
- **Assume**: Components will fail at some point
- **Goal**: Minimize the impact of failures
- **Detection**
  - Monitoring
  - Redundancy
- **Response**
  - Graceful degradation (fail-safe)
  - Redundancy (fail over)
- **Containment**
  - Decoupling & isolation

# DETECTION: MONITORING



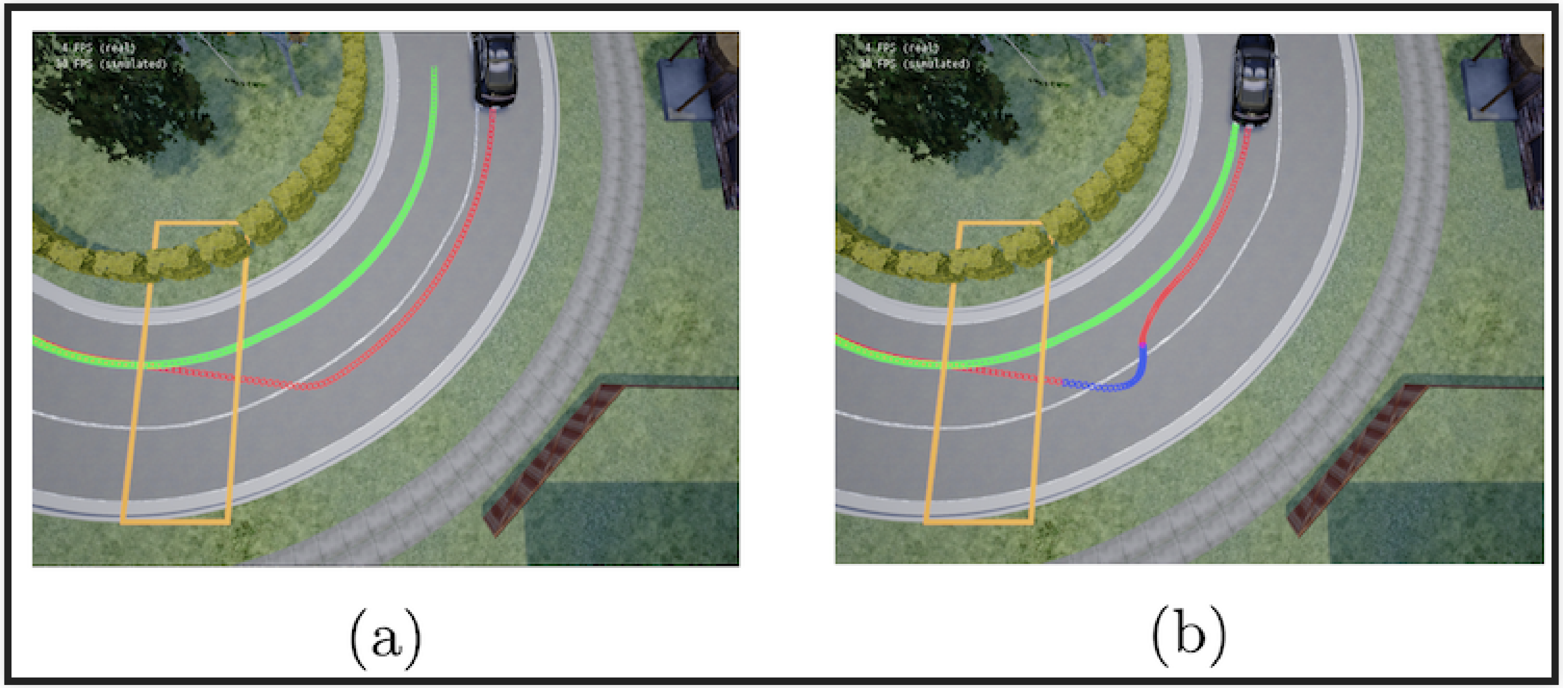

- **Goal**: Detect when a component failure occurs
- **Monitor**: Periodically checks the output of a component for errors
    - Challenge: Need a way to recognize errors
    - e.g., corrupt sensor data, slow or missing response
- **Doer-Checker** pattern
    - Doer: Perform primary function; untrusted and potentially faulty
    - Checker: If doer output faulty, perform corrective action (e.g., default safe output, shutdown); trusted and verifiable

# DOER-CHECKER EXAMPLE: AUTONOMOUS VEHICLE




- ML-based controller (**doer**): Generate commands to maneuver vehicle
  - Complex DNN; makes performance-optimal control decisions
- Safe controller (**checker**): Checks commands from ML controller; overrides it with a safe default command if maneuver deemed risky
  - Simpler, based on verifiable, transparent logic; conservative control

# DOER-CHECKER EXAMPLE: AUTONOMOUS VEHICLE



(a) (b)

- Yellow region: Slippery road, causes loss of traction
- ML-based controller (**doer**): Model ignores traction loss; generates unsafe maneuvering commands (a)
- Safe controller (**checker**): Overrides with safe steering commands (b)

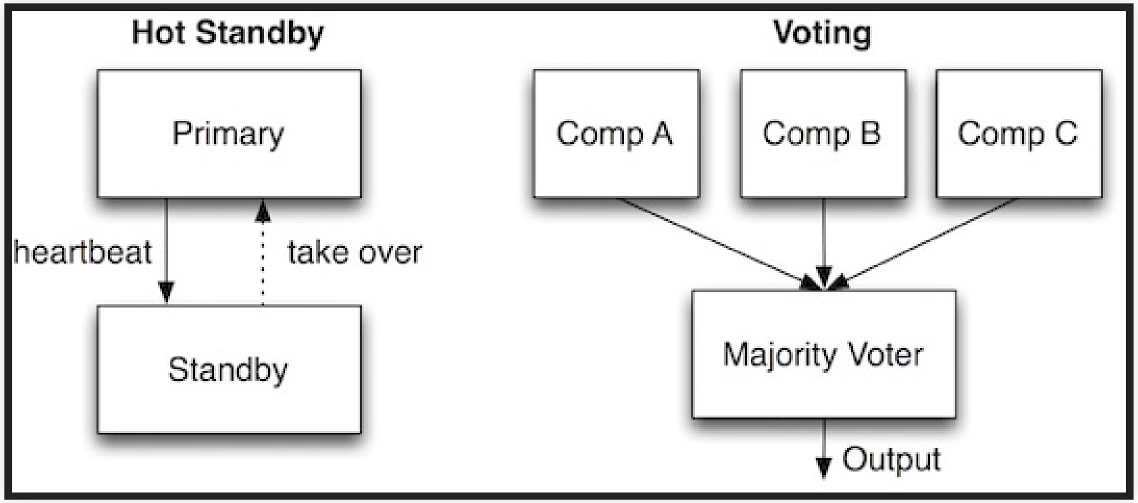
*Runtime-Safety-Guided Policy Repair*, Intl. Conference on Runtime Verification (2020)

# RESPONSE: GRACEFUL DEGRADATION (FAIL-SAFE)

[redacted]

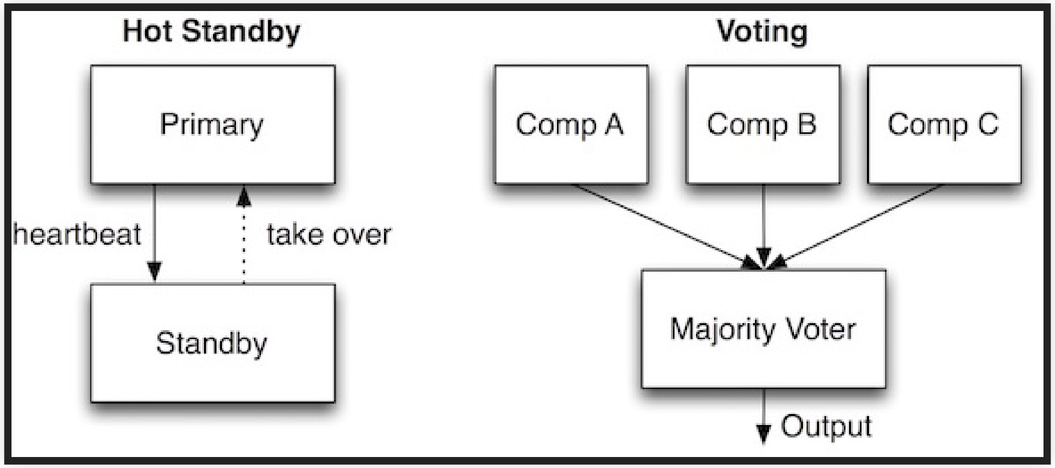
- **Goal**: When a component failure occurs, continue to provide safety (possibly at reduced functionality and performance)
- Relies on a monitor to detect component failures
- Example: Perception in autonomous vehicles
    - If Lidar fails, switch to a lower-quality detector; be more conservative
    - **But what about other types of ML failures? (e.g., misclassification)**

# DETECTION & RESPONSE: REDUNDANCY




- **Detection**: Compare output from redundant components
- **Reseponse:** When a component fails, continue to provide the same functionality
- **Hot Standby**: Standby watches & takes over when primary fails
- **Voting**: Select the majority decision
- Caution: Do components fail independently?
    - Reasonable assumption for hardware/mechanical failures
    - **Q. What about software?**

# DETECTION & RESPONSE: REDUNDANCY




- **Detection**: Compare output from redundant components
- **Reseponse:** When a component fails, continue to provide the same
- **Hot Standby**: Standby watches & takes over when primary fails
- **Voting**: Select the majority decision
- Caution: Do components fail independently?
    - Reasonable assumption for hardware/mechanical failures
    - Software: Difficult to achieve independence even when built by different teams (e.g., N-version programming)
    - **Q. ML components?**

# RESPONSE: HUMAN IN THE LOOP

*Less forceful interaction, making suggestions, asking for confirmation*

- AI and humans are good at predictions in different settings
    - AI better at statistics at scale and many factors
    - Humans understand context and data generation process and often better with thin data
- AI for prediction, human for judgment?
- But be aware of:
    - Notification fatigue, complacency, just following predictions; see *Tesla autopilot*
    - Compliance/liability protection only?
- Deciding when and how to interact
- Lots of UI design and HCI problems

**Examples?**

Speaker notes

Cancer prediction, sentencing + recidivism, Tesla autopilot, military "kill" decisions, powerpoint design suggestions

# RESPONSE: UNDOABLE ACTIONS

*Design system to reduce consequence of wrong predictions, allowing humans to override/undo*

**Examples?**

Speaker notes

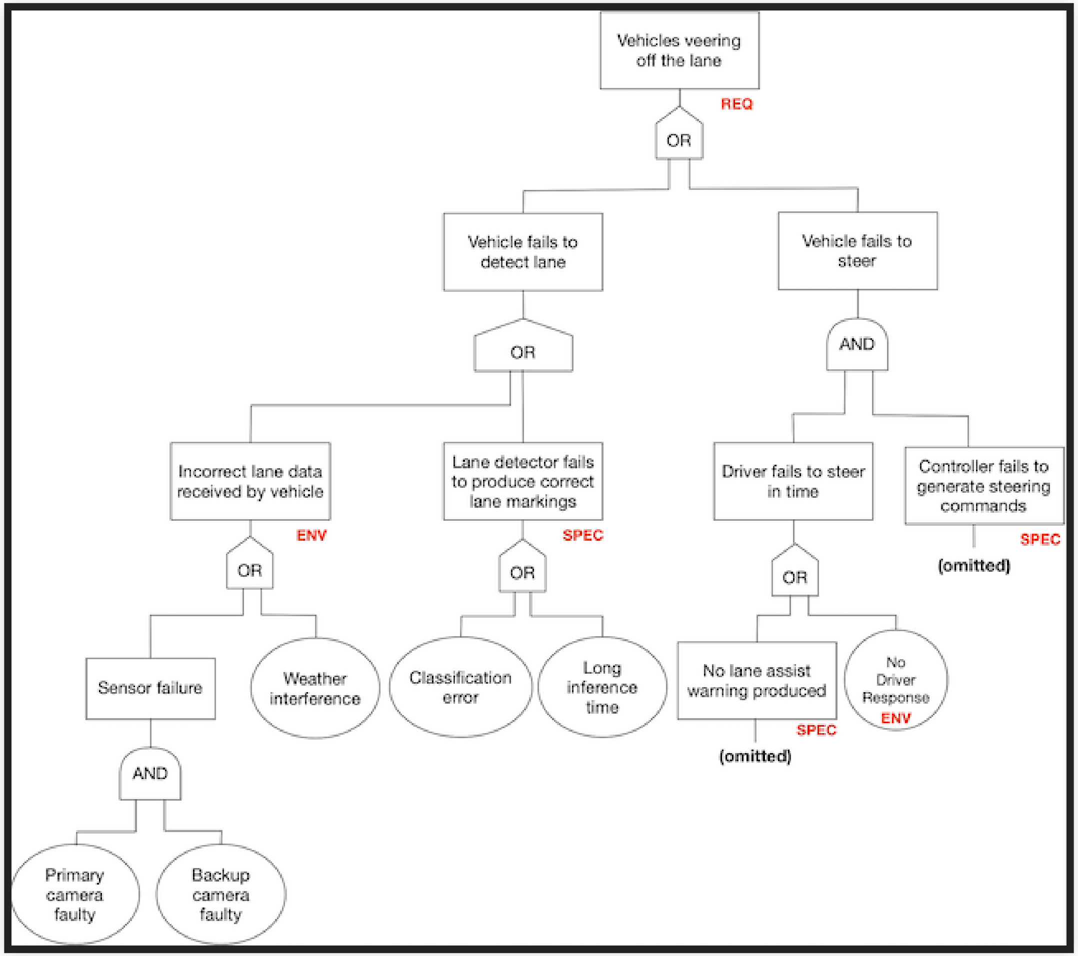
Smart home devices, credit card applications, Powerpoint design suggestions

# EXAMPLE: LANE ASSIST

## Q. Possible mitigation strategies?

# EXAMPLE: LANE ASSIST

## Q. Possible mitigation strategies?



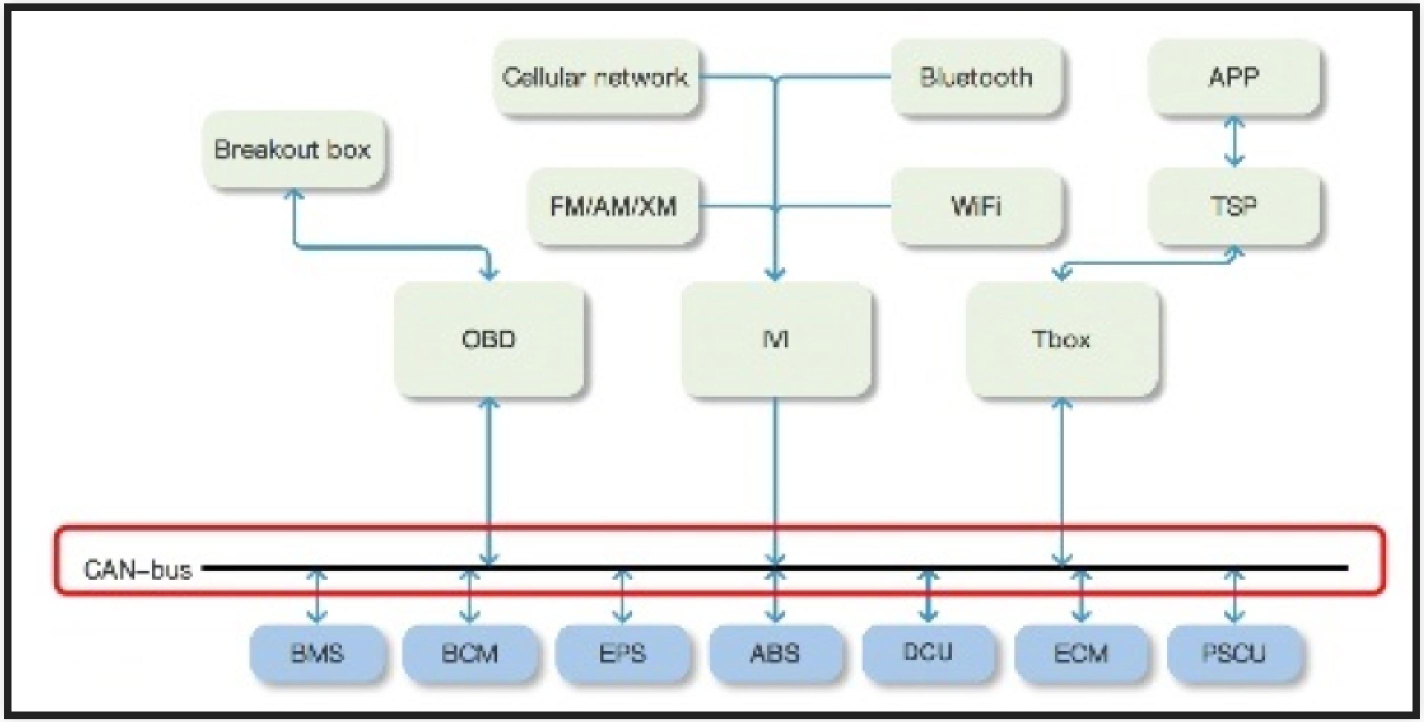
# CONTAINMENT: DECOUPLING & ISOLATION

- **Goal**: Faults in a low-critical (LC) components should not impact high-critical (HC) components

# POOR DECOUPLING: USS YORKTOWN (1997)

- Invalid data entered into DB; divide-by-zero crashes entire network
- Required rebooting the whole system; ship dead in water for 3 hours
- **Lesson**: Handle expected component faults; prevent propagation

# POOR DECOUPLING: AUTOMOTIVE SECURITY




- Main components connected through a common CAN bus
    - Broadcast; no access control (anyone can read/write)
- Can control brake/engine by playing a malicious MP3

*Experimental Security Analysis of a Modern Automobile*, Koscher et al., (2010)

# CONTAINMENT: DECOUPLING & ISOLATION

- Goal: Faults in a low-critical (LC) components should not impact high-critical (HC) components
- Apply the principle of least privilege
  - LC components should be allowed to access min. necessary functions
- Limit interactions across criticality boundaries
  - Deploy LC & HC components on different networks
  - Add monitors/checks at interfaces
- Is AI in my system performing an LC or HC task?
  - If HC, can we "demote" it into LC?
  - Alternatively, replace HC AI components with non-AI ones with stronger guarantees
  - **Q. Examples?**

# SUMMARY

- Accept that ML components will make mistakes
- Use risk analysis to identify and mitigate potential problems
- Design strategies for detecting and mitigating the risks from mistakes by AI