A User-Centric Perspective on Robust Autonomy in Unstructured Environments

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Texas A&M: Leader in Engineering

- 3rd in Engineering Research (MIT, Georgia Tech)
- 144km from Houston
- 68,825 students
  - 20,000 graduate students
  - 16,000 Undergraduates in Engineering
  - 500 faculty in engineering

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TAMU: Leader in Disaster Practice

Disaster City, College Station, TX

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Outline

- Unstructured environments
- Why they are hard for platform design
- Why they are hard for users
- Where autonomy has not helped and why

Center for Robot-Assisted Search and Rescue

RESPONSES 2001-2018

What You Could See or Could Infer

Unstructured work envelopes

- Deconstructed: structure is destroyed or damaged; a priori knowledge is likely to be wrong
- Irregular: physical characteristics are not uniform
- Unpredictable
- Temporal variability: may change over time (e.g., day, night, fog, …)

Extreme conditions

- Size or scale
- Operating at the boundaries of nominal design parameters
- Emergency: time pressure, consequences of poor performances

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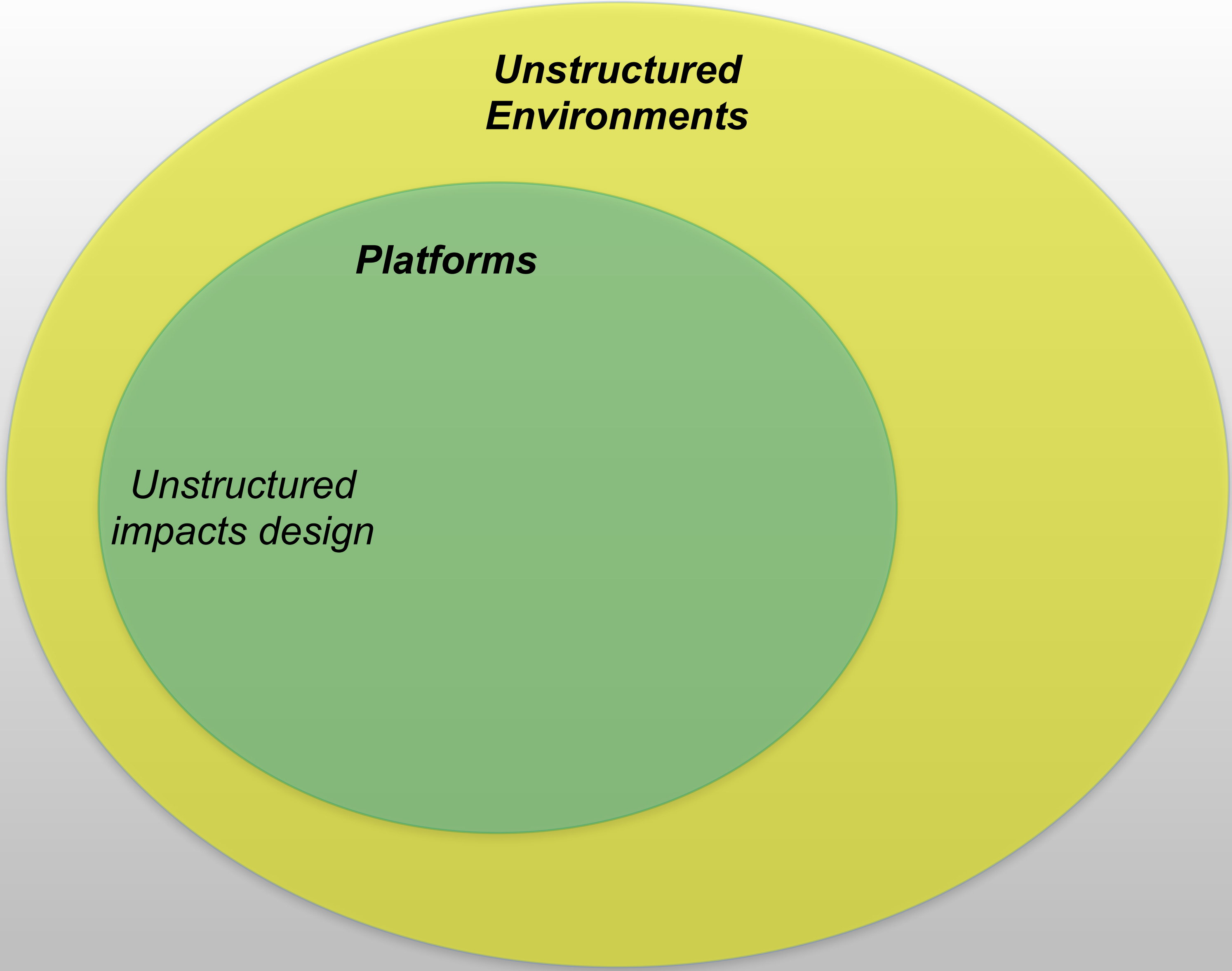
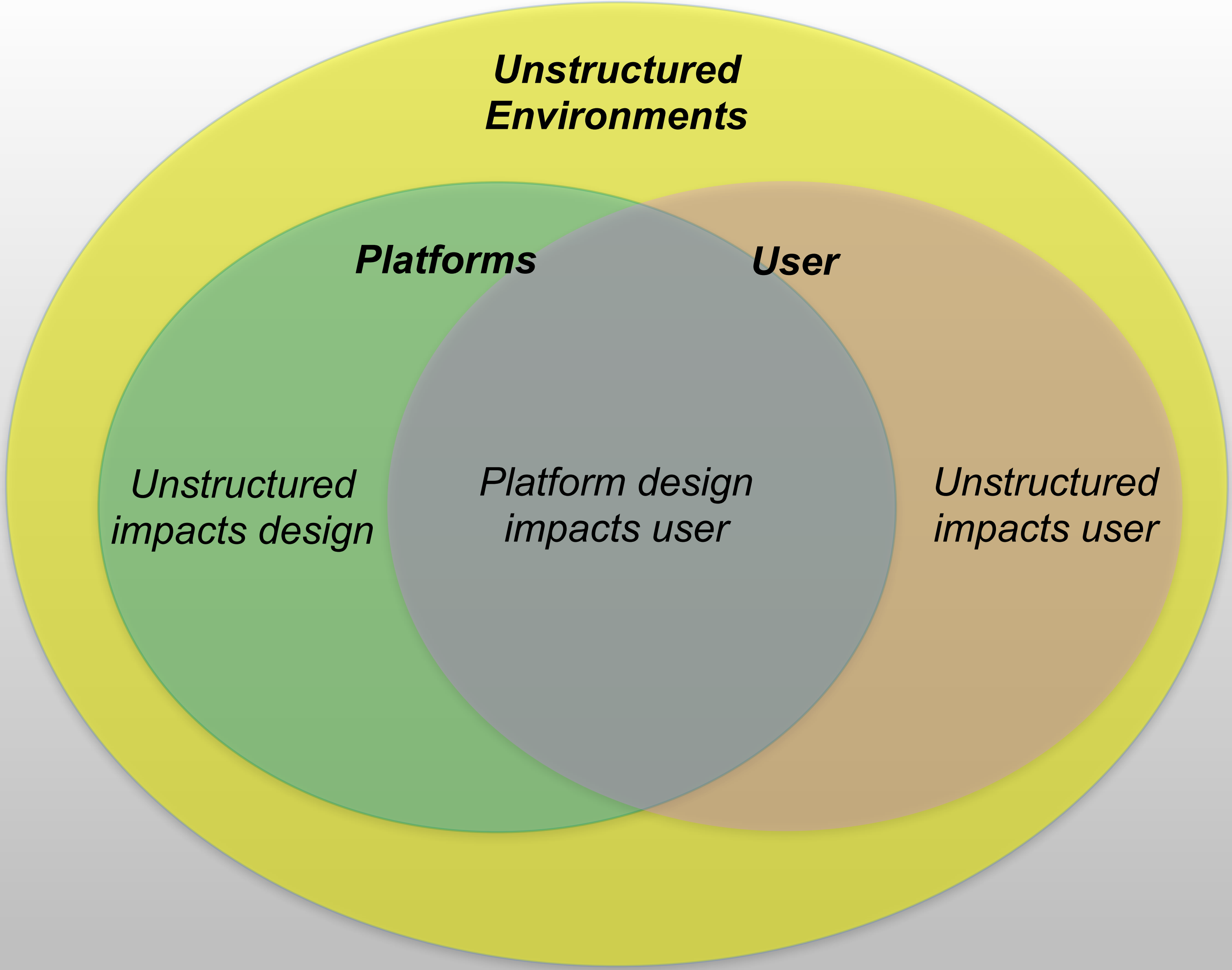
What You Didn't See: They All Were Teleoperated

- Very hard to be autonomous in real time in these conditions
- Humans notice things, make notes for extraction
- Lots of people looking at displays at the same time!
- **And operators turn off the autonomy…**


Unstructured Environments
Platforms
Unstructured impacts design



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Platform Design Impacts User

- User interface
- Sensors and mountings
  - Inherent remote presence, sensemaking, and transparency
  - Ex. Midas

Platform Impacts

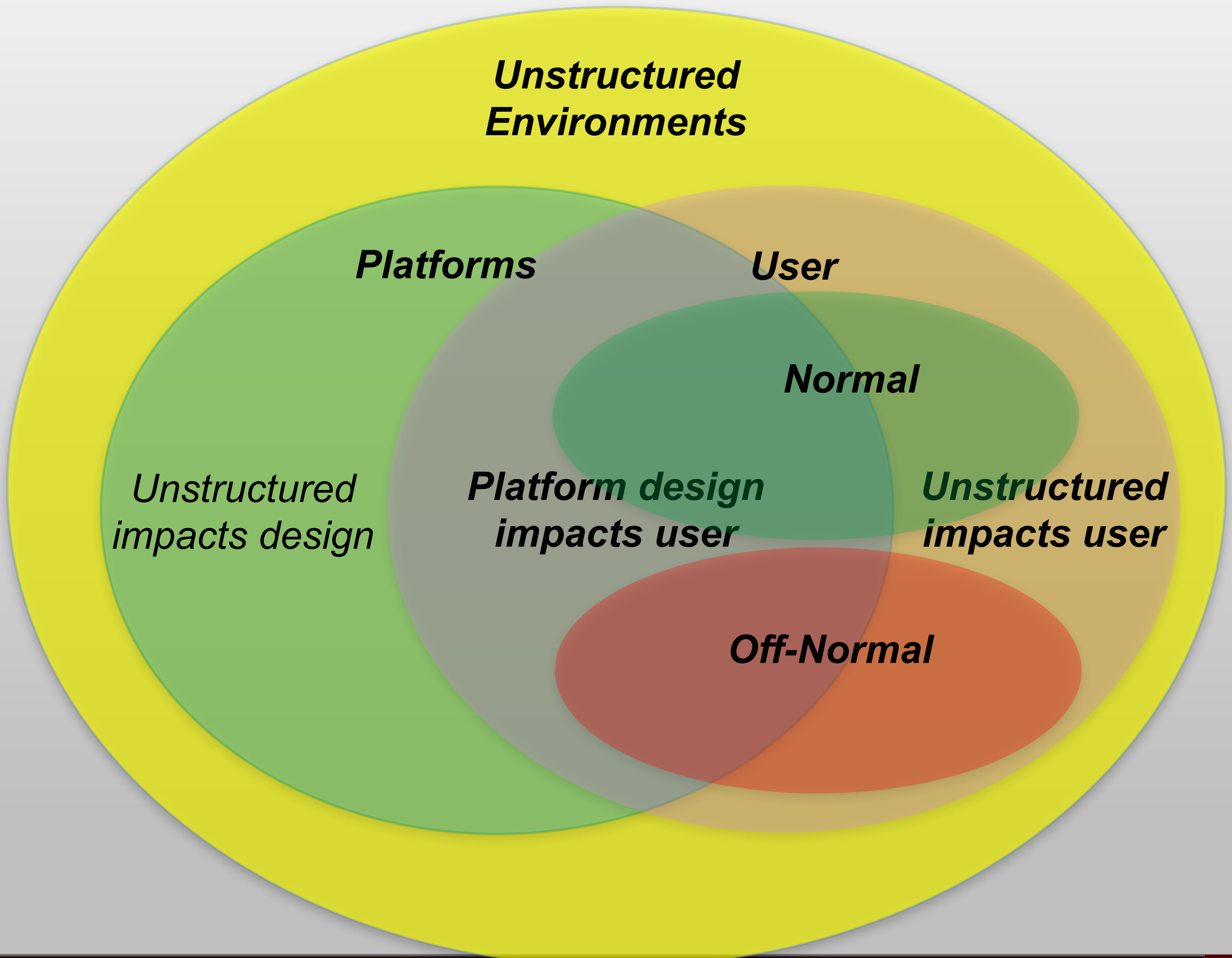
- ”Unnatural” viewpoints for the user
- Environment is unknown, partially known, or deconstructured
- Unstructured Environments Effectively Double Cognitive Workload
  - High cognitive load, effectively doubles
  - 2 heads are 9 times more effective than 1

Unstructured In General Impacts User

- Physiological
  - e.g., Fatigue
- Psychological
  - e.g., Pressure

Increases possibility of failures

Impact Depends on Normal, Off-Normal



Five Ways Applications Can Be Off-Normal

- **Robot**
  - different robot or have added a new payload or manipulator
- **Mission**
  - new applications that have not been trained for such as lowering a sensor through a guardrail; a new sequence of tasks. of which the robot and operator have proficiency in; or it can be a novel task and thus proficiency is unknown
- **Robot work envelope**
  - may be more cluttered, deconstructed than normal; smaller or more confined
- **Operator**
  - Skills: skills, training, experience different
  - State: May be under pressure, may not be well-rested or healthy, may distrust due to prior bad experiences
- **Operator work envelope**
  - a new location or the type of area may be more limited in space to set up and move around in, physically uncomfortable, operator may be wearing PPE that have little experience with

Application or Use

Normal

Robot
Mission or task
Robot work envelope
Operator work envelope
Operator

Off-Normal

Novel

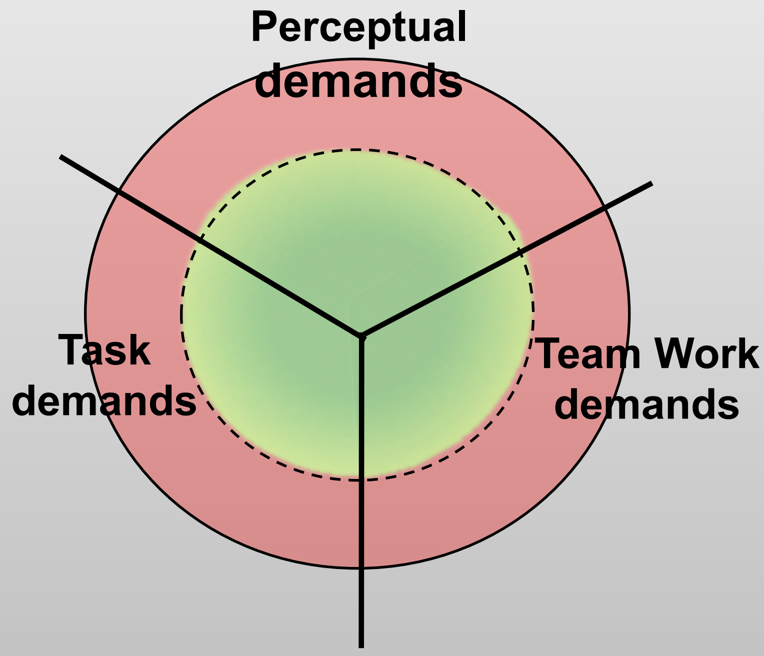
New Robot OR
New Mission or task OR
New Robot work envelope OR
New Operator work envelope **OR**
Decreased Operator capacity

Novel:

One or more of the 5 factors has changed

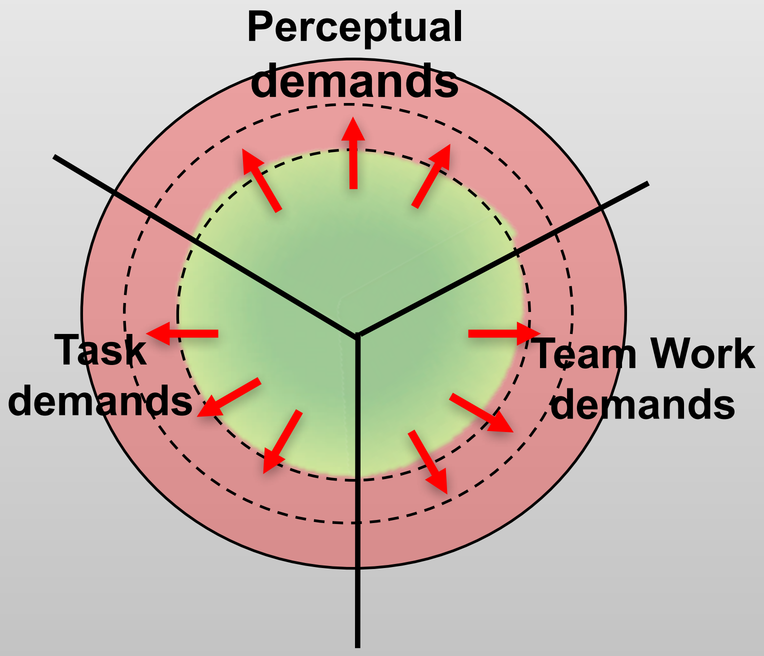
Capacity: Physiological and psychological state

3 Categories of Drains on Cognitive Resources (after Wickens Multiple Resource Theory)



“Novel” Changes Cognitive Resources

- If the demands are in the “green” area, all is well, but if ***demands expand*** out, then get into “red” or more error-prone



Midas Mine Disaster 2007: Example of Demands Exceeding Capacity

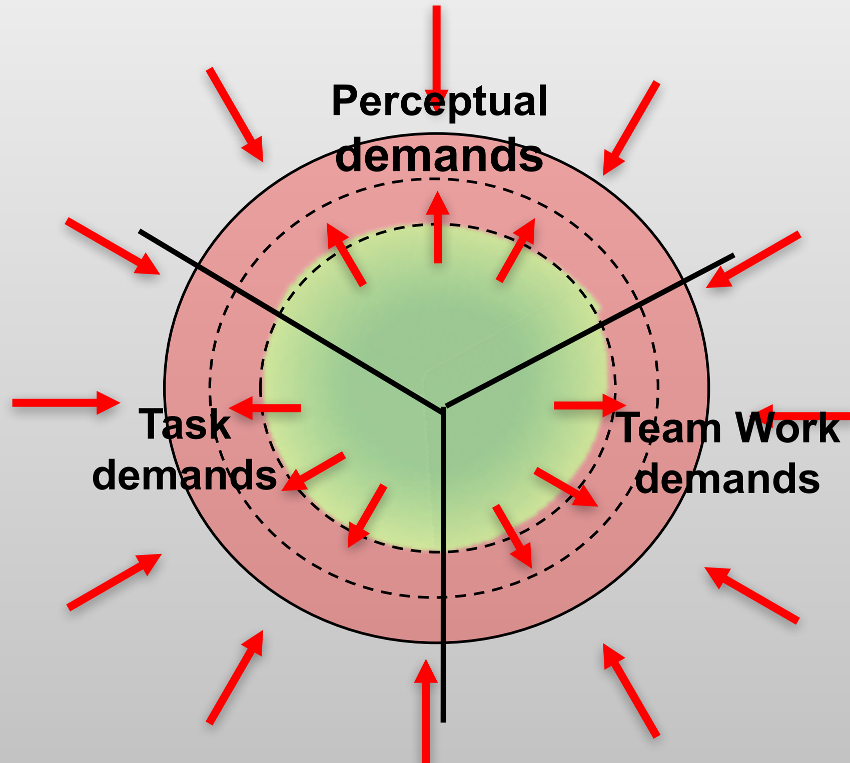
- Perceptual demands
- Task demands
- Team work demands

Example of Demands Exceeding Capacity

- Perceptual demands
- Task demands
- **Team work demands**

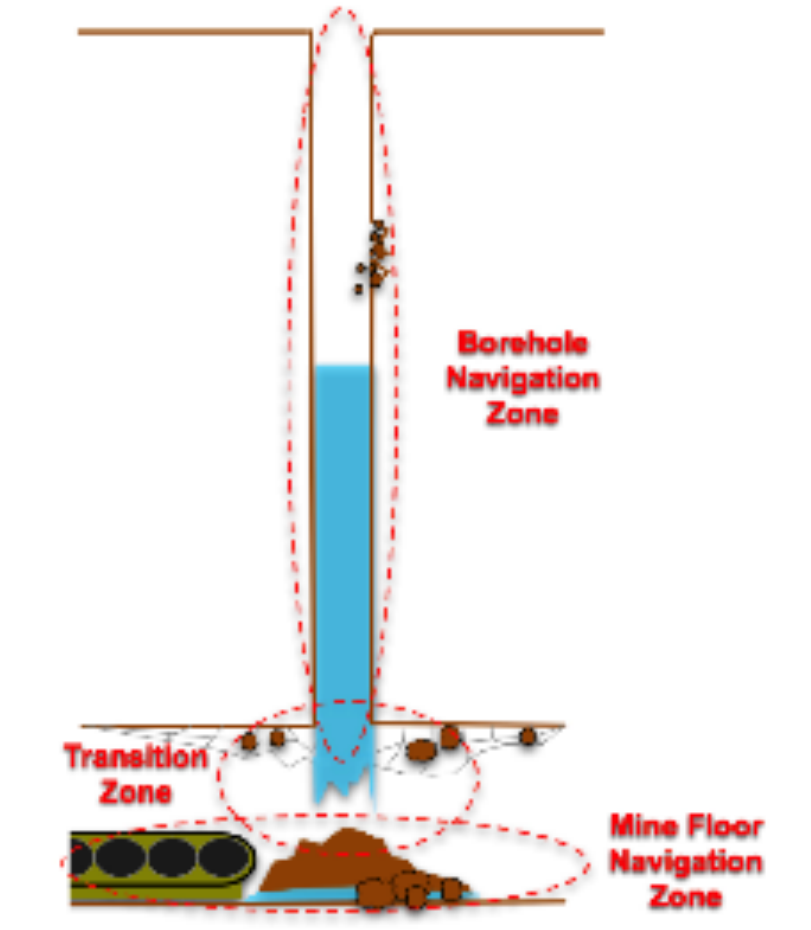
But Other Factors ***Decrease*** the Circle of Operator Capacity

- Physiological
  - e.g., Lack of sleep, rusty on skills, wearing PPE
- Psychological
  - e.g., Consequences, worry



physiological and psychological factors

Crandall Canyon Mine (2007)



Note: 2 distinct navigation regions

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Crandall Canyon 2007

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Application or Use

Normal

Robot
Mission or task
Robot work envelope
Operator work envelope
Operator

Off Normal

Emergency:

Operator capacity has decreased and maybe 1 or more of the other factors

Novel

New Robot OR
New Mission or task OR
New Robot work envelope OR
New Operator work envelope **OR**
Decreased Operator capacity

Emergency

New Robot OR
New Mission or task OR
New Robot work envelope OR
New Operator work envelope **AND**
Decreased Operator "capacity"

Capacity: Physiological and psychological state

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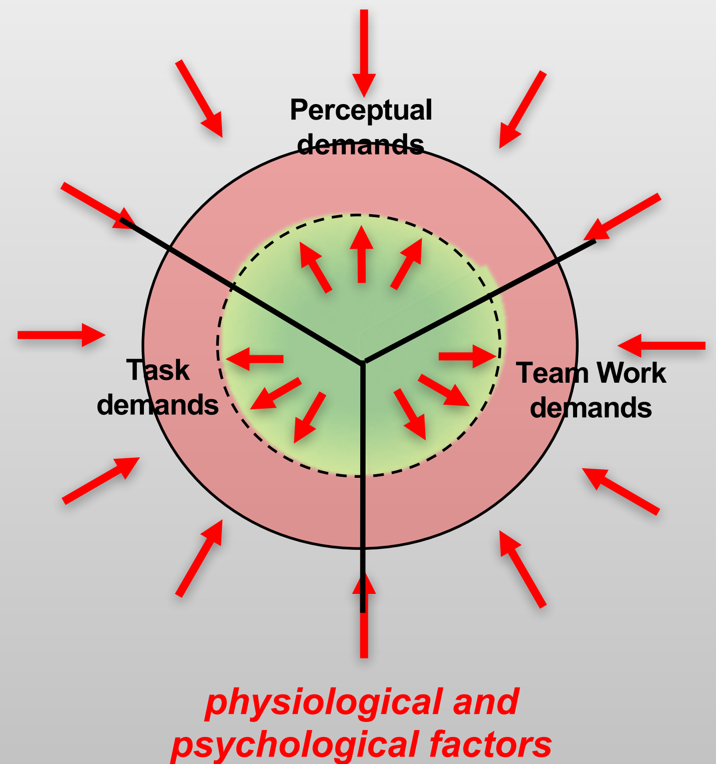
Worst Case is to Try New Things During an Emergency



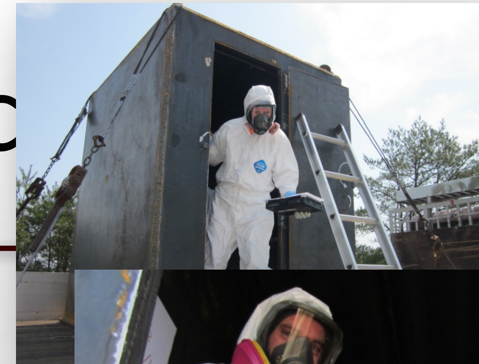
Autonomy Should Help

- But not if it is unreliable or unpredictable
- 4 Examples

Fukushima Daiichi (2011)

Emergency
New Robot OR New Mission or task OR New Robot work envelope OR New Operator work envelope **AND** **Decreased Operator "capacity"**

Fukushima Daiic



Emergency
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Fukushima Daiichi (2011)

Emergency
New Robot OR New Mission or task OR New Robot work envelope OR New Operator work envelope **AND** **Decreased Operator "capacity"**

- Existing robot
- Different mission
- Different robot work envelope
- Different operator work envelope- including working with SME
- Jet lag, stress, PPE, and a major secondary quake

Fukushima Daiichi (2011)

Emergency
New Robot OR New Mission or task OR New Robot work envelope OR New Operator work envelope **AND** **Decreased Operator "capacity"**

- Existing robot
- Different mission
- Different robot work envelope
- Different operator work envelope- in… ng … E, and a …major secondary quake

Turned off the navigational autonomy due to lack of visibility

Hurricane Harvey (2017)

Emergency
New Robot OR New Mission or task OR New Robot work envelope OR New Operator work envelope **AND** **Decreased Operator “capacity”**

Hurricane Harvey (2017)

Emergency
New Robot OR New Mission or task OR New Robot work envelope OR New Operator work envelope **AND** **Decreased Operator “capacity”**

- Existing robots
- Familiar missions
- Familiar robot work envelopes
- Familiar operator work envelopes- including working with SME
- Fatigue, a bit rusty, pressure due to cost

DJI Matrice 600

Emergency
New Robot OR New Mission or task OR New Robot work envelope OR New Operator work envelope **AND** **Decreased Operator "capacity"**

Hurricane Harvey (2017)

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New Robot OR New Mission or task OR New Robot work envelope OR New Operator work envelope **AND** **Decreased Operator "capacity"**

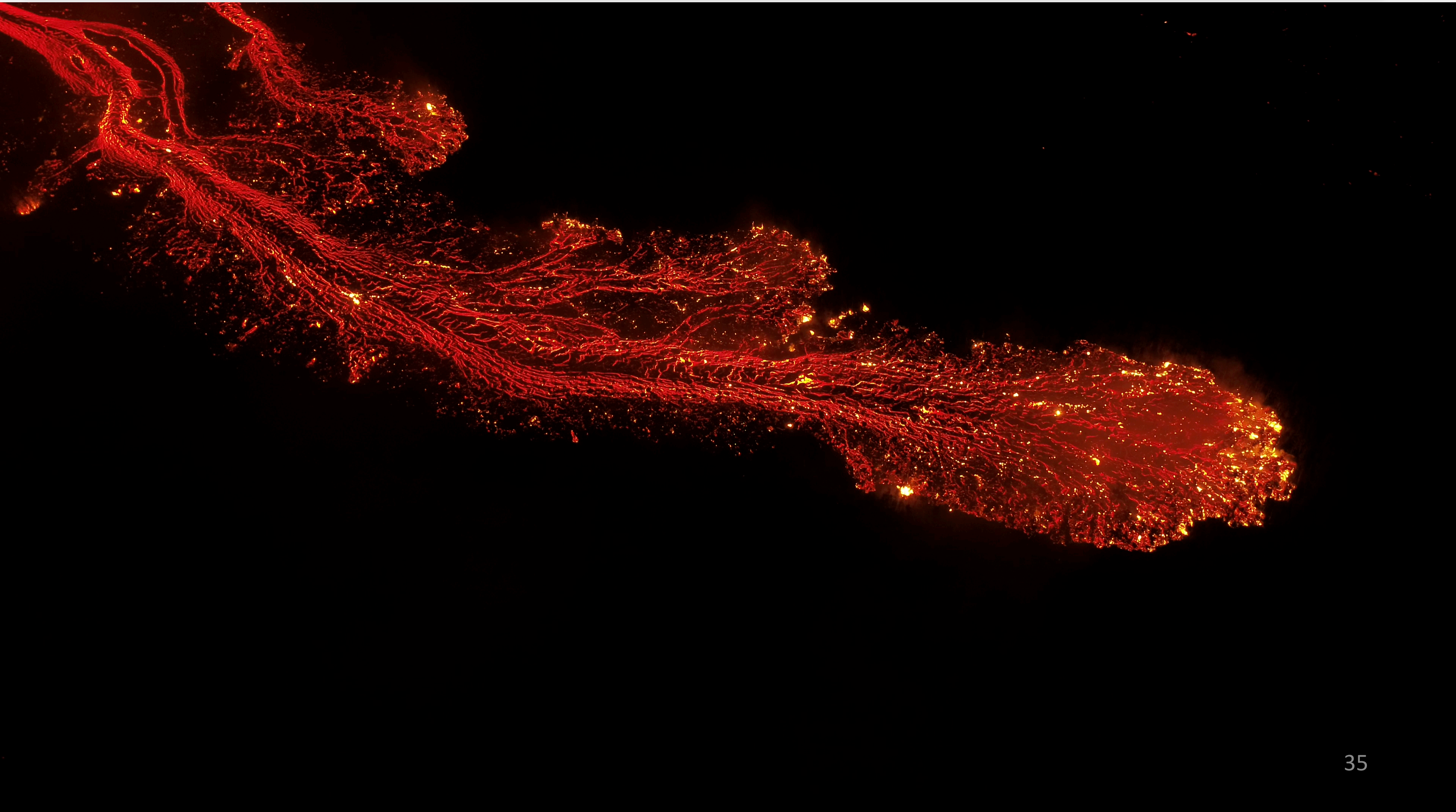
- Existing robot
- Familiar mission
- Familiar robot work envelope
- Familiar operator work envelope- in ng
  ety, pressure
  due to cost

Discontinued use of M600 due to lack of trust because of bugs

Kilauea Volcanic Eruption (2018)

Emergency
New Robot OR New Mission or task OR New Robot work envelope OR New Operator work envelope **AND** **Decreased Operator "capacity"**

Kilauea Analysis
(with Profs. D. Merrick (FSU), A. Wang, NSF)



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Kilauea Volcanic Eruption (2018)

Emergency
New Robot OR New Mission or task OR New Robot work envelope OR New Operator work envelope **AND** **Decreased Operator "capacity"**

- Existing robot
- Familiar mission
- Challenging robot work envelope and at night and 1,000 ft
- Unsafe operator work envelope
- Extreme fatigue

Kilauea Volcanic Eruption (2018)

Emergency
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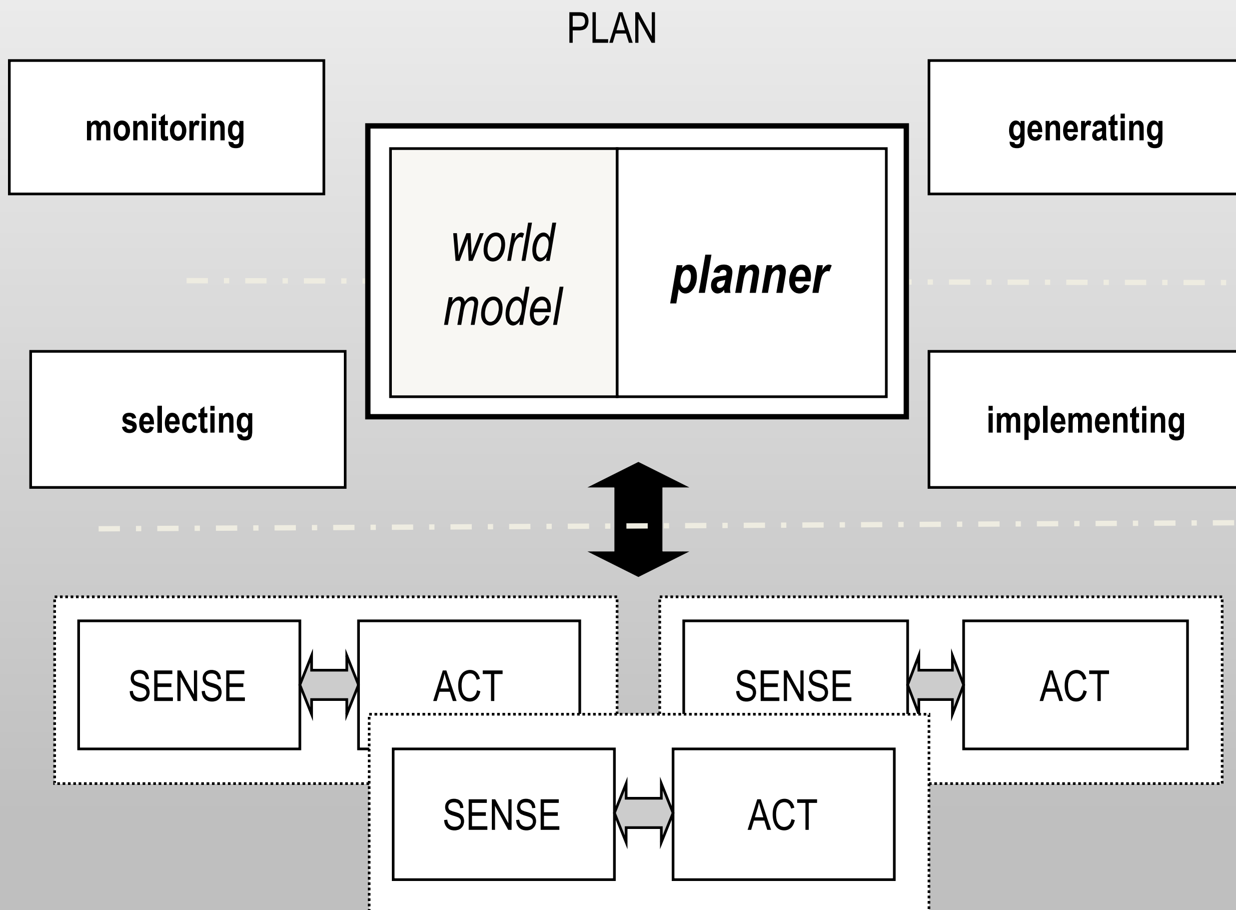
- Challenging robot work envelope and at night
- Unsafe operator work envelope

Took 3 flights to get the autonomous mapping package to work correctly

We Tend To Think of Implementing, Not Generating, Selecting, or Monitoring



Not just navigational autonomy…

- Computer Vision/Machine Learning for the Blanco River Floods (2015)
- 21 people missing, presumed swept away over a 5 mile stretch of river and flood plain
- Large number of volunteers with drones collecting data
- Need to examine high resolution images

Didn't Work: Different seasons, different vegetation

Blanco River, June 2015

Camp Creek Lake, Feb 2019

Didn’t Work: Different seasons, different vegetation

Blanco River, June 2015

Camp Creek Lake, Feb 2019

No way to predict what will work and won’t want

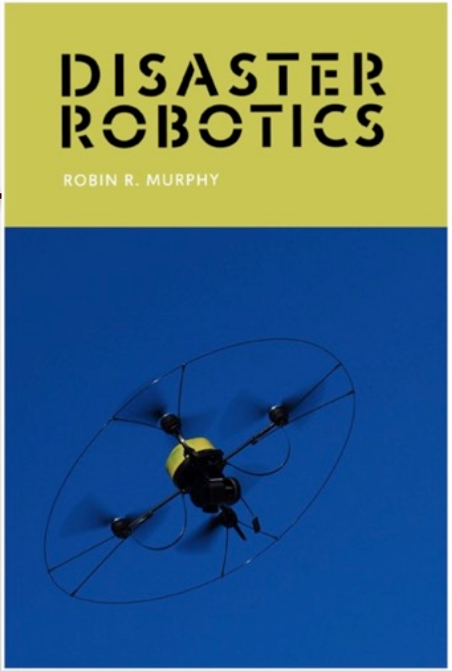
Robust Autonomy Means…

- It is transparent; what it is doing, not necessarily how
- It is reliable and error-free
- It covers the entire task, not just the easy part
- It indicates whether it will be successful: expected false positive, false negative rates

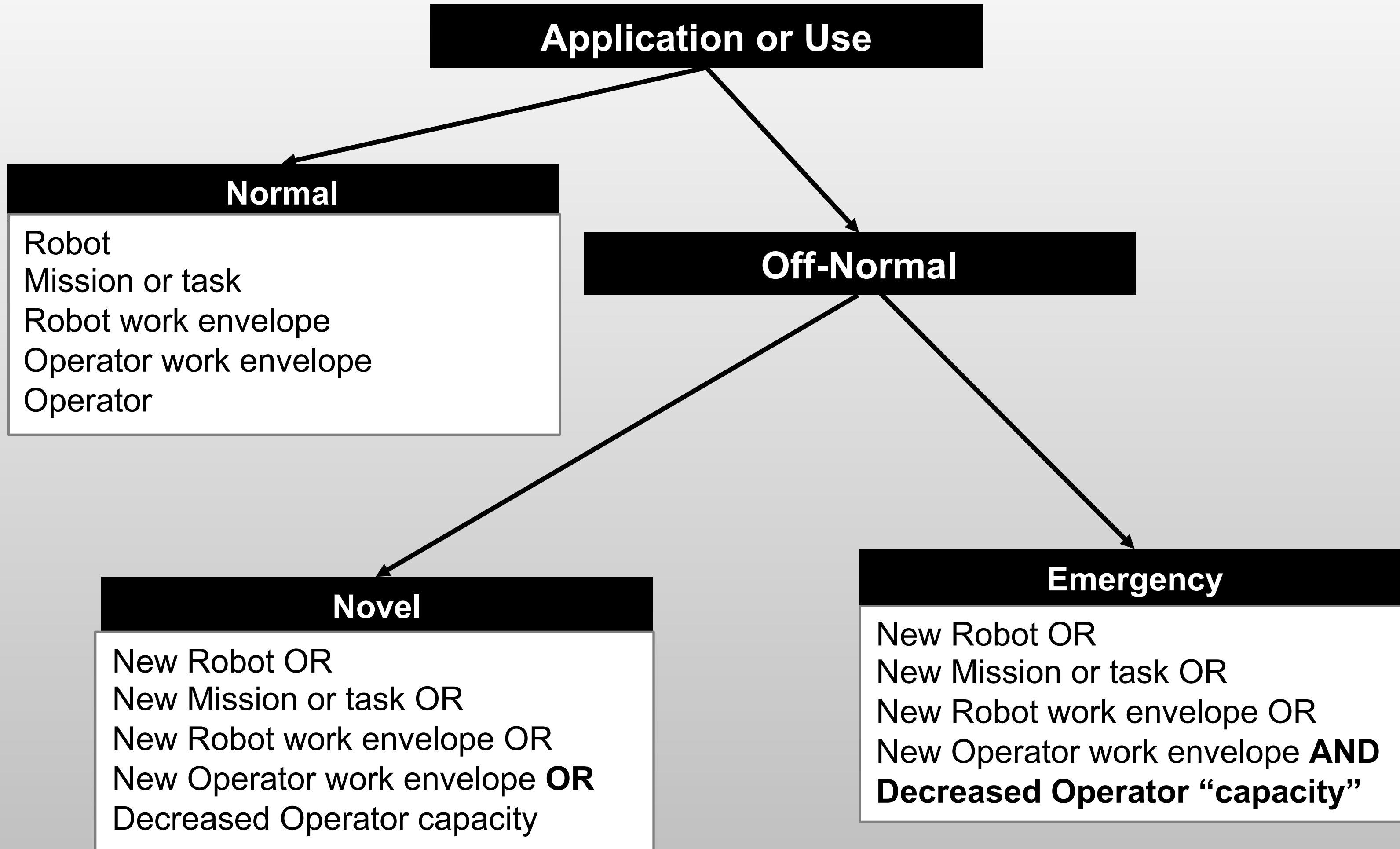
Summary

- Unstructured environments are hard on platforms, harder on users
- Novel applications may decrease operator's cognitive capacity, but an emergency definitely will
- Autonomy won't help if it is not robust and useful from a systems perspective

Additional Resources



- *Disaster Robotics*, MIT Press, Murphy 2014
- *User Interfaces: Disaster Robotics: Results from the ImPACT Tough Robotics Challenge*, Springer, ed. Tadokoro 2019
- Off-normal: AHFE papers



Capacity: Physiological and psychological state

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