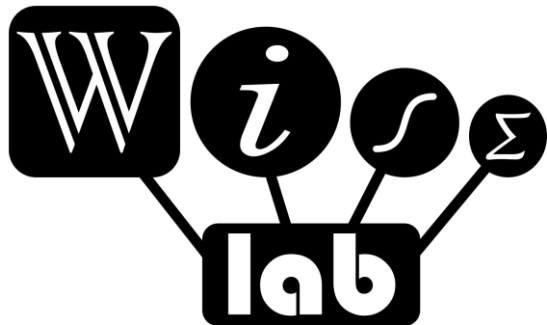


Towards a Framework to Manage Perceptual Uncertainty for Safe Automated Driving

Krzysztof Czarnecki & Rick Salay

Waterloo Intelligent Systems Engineering Lab
Electrical and Computer Engineering Department



UNIVERSITY OF
WATERLOO

WatCAR 
driving innovation

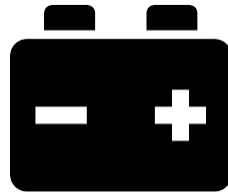
ADS Hazard Sources



Mature best practices

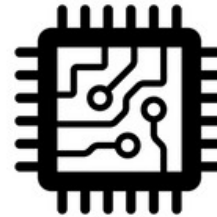


Mechanical faults



Electrical faults

ISO 26262



Computer HW faults

01100
10110
11110

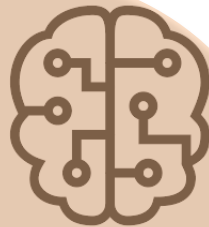
Computer SW faults



(ISO / PAS 21448)



Sensor noise & limitations



Machine learning errors



Inadequate driving behavior



DDT fallback failures

SAE J3061

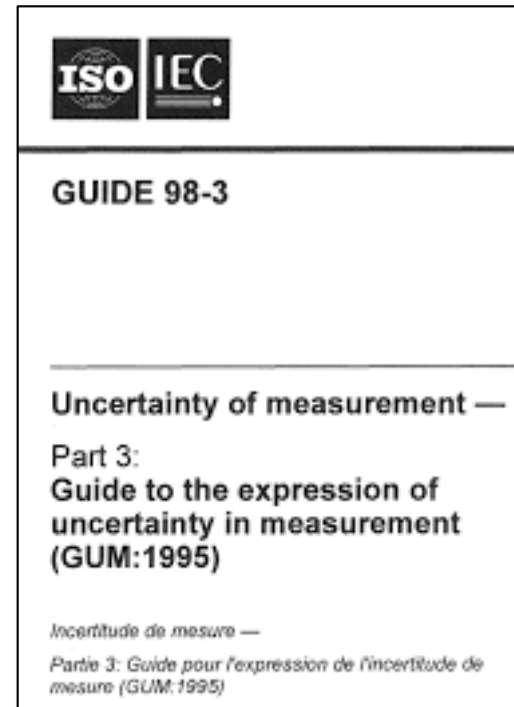


Cyber attacks

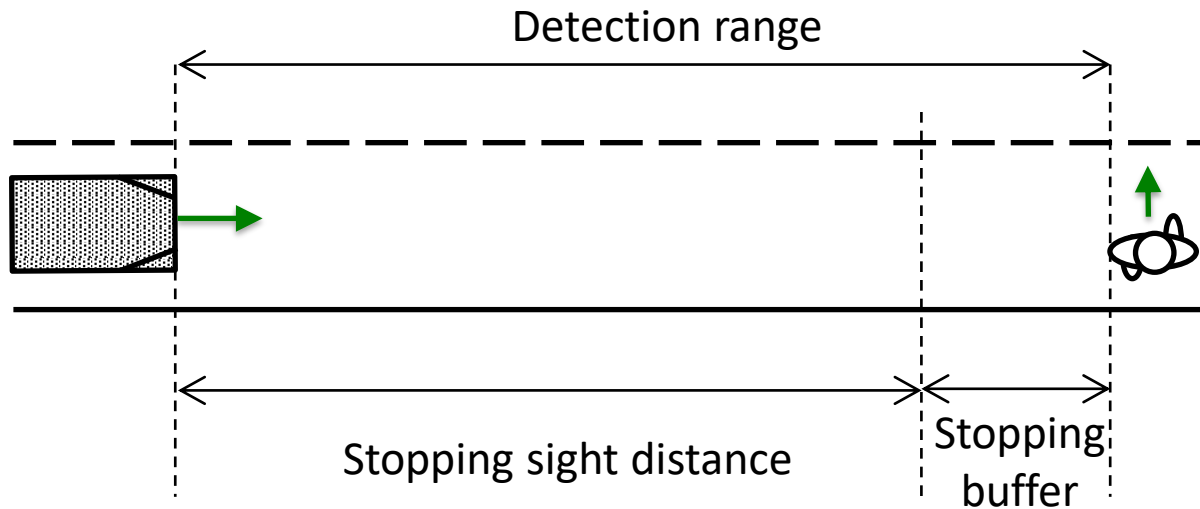
Perception (measuring world state)

Guide to the Expression of Uncertainty in Measurement (GUM)

- True accuracy unknowable
 - Accuracy in ML wrt. test set only
- Must estimate uncertainty

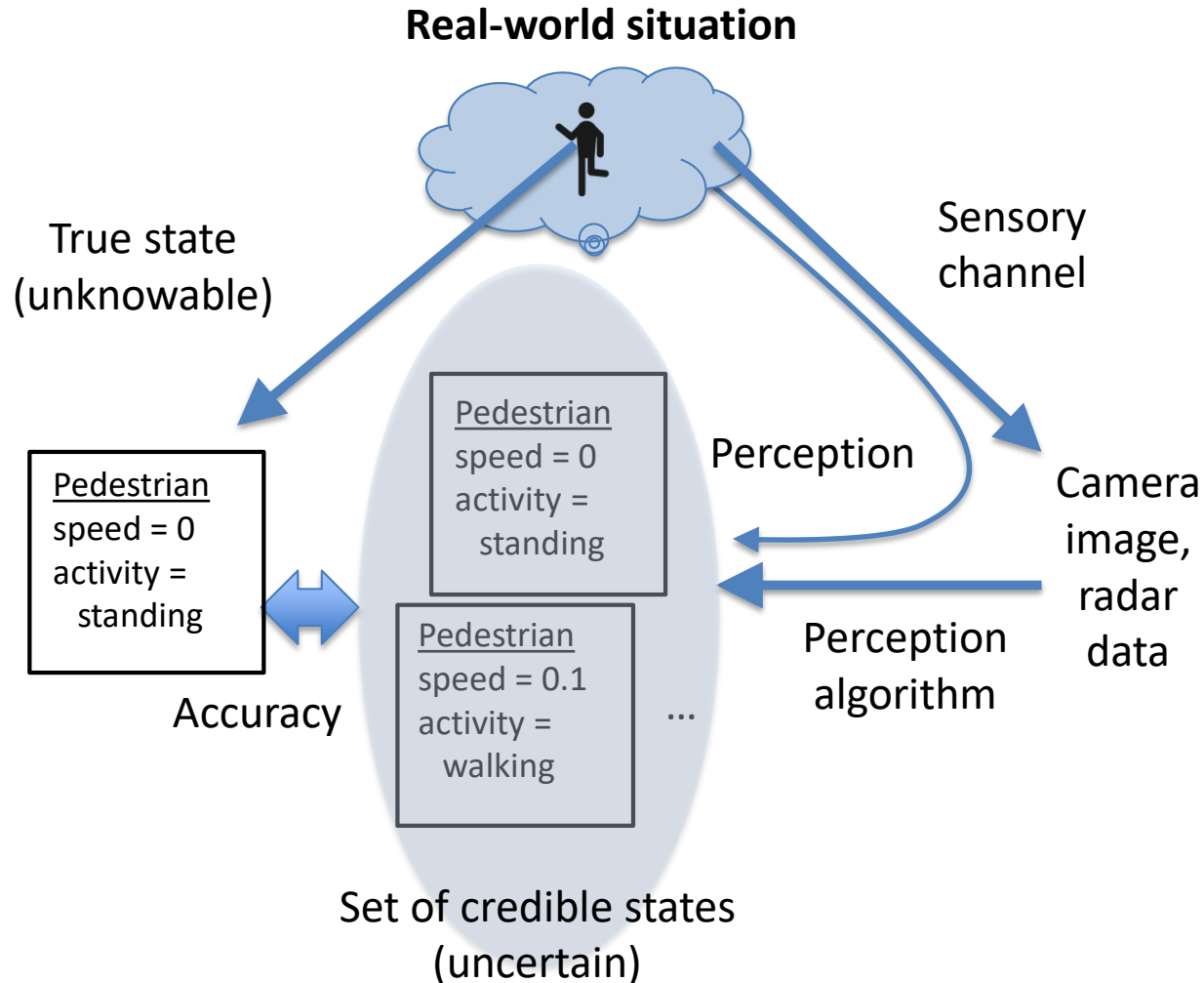


Sample Scenario-Dependent Perception-Performance Safety-Requirement Spec

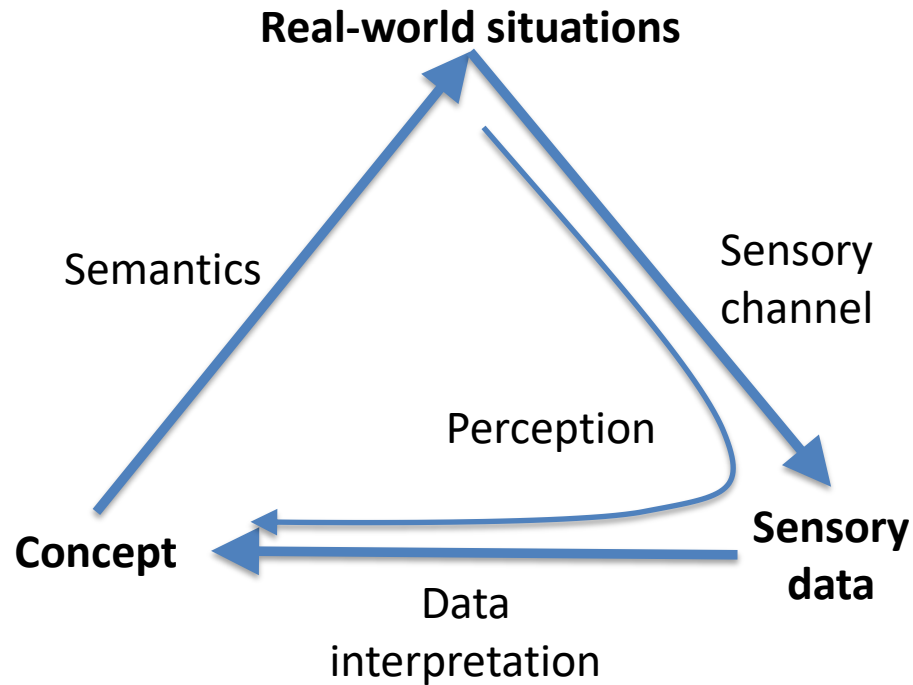


Detect pedestrians on the roadway
within range 10 m and with maximum perception-reaction delay of 0.5 s
with missed detection **probability** of 10^{-9} or less
with localization **uncertainty** of ± 0.5 m or better
within ODD conditions

Perception Triangle (Instance level)



Perceptual Triangle (Domain level)



Perceptual Triangle When Using Supervised ML

Development

Development situations and scenarios

Partial semantics (examples)

Training & testing

Sensory channel

Sensory data

Concept

Data labeling

Model class selection, training & testing

Trained Model

Operation

Operational situations and scenarios

Resulting perception

Inference

Sensory channel

Sensory data

Inferred state

Concept

Factors Influencing Uncertainty

Development

Development situations and scenarios

Partial semantics (examples)

Training & testing

Sensory channel

Sensory data

Data labeling

Model class selection, training & testing

Operation

Operational situations and scenarios

Resulting perception

Sensory channel

Inference

Concept

Sensory data

Inferred state

Trained Model

F1: Conceptual Uncertainty

Development

Development situations and scenarios

Partial semantics (examples)

F1

Training & testing

Sensory channel

Sensory data

Data labeling

Model class selection, training & testing

Trained Model

Operation

Operational situations and scenarios

Resulting perception

Sensory channel

Inference

Concept

Sensory data

Inferred state

F1: Conceptual Uncertainty Pedestrian or Cyclist?



F2: Development Scenario Coverage

Development

Development situations and scenarios

Partial semantics (examples)

F2

Sensory channel

Training & testing

Sensory data

Concept

Data labeling

Model class selection, training & testing

Operation

Operational situations and scenarios

Resulting perception

Sensory channel

Inference

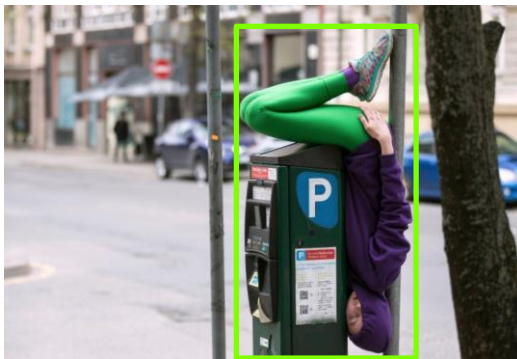
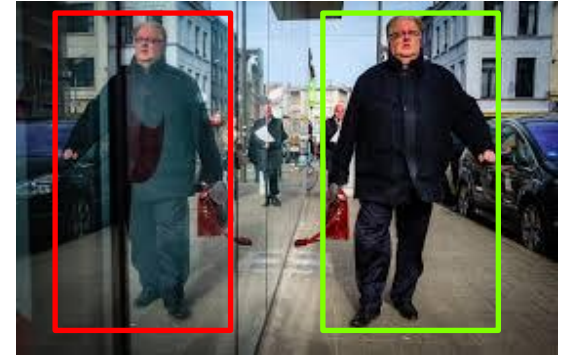
Sensory data

Concept

Inferred state

Trained Model

F2: Development Scenario Coverage



F3: Scene Uncertainty

Development

Development situations and scenarios

Partial semantics (examples)

(F2)

(F3)

Sensory channel

Training & testing

Sensory data

Concept

Data labeling

Model class selection, training & testing

Trained Model

Operation

Operational situations and scenarios

Resulting perception

Sensory channel

Inference

Concept

Inferred state

Sensory data

F3: Scene Uncertainty



F4: Sensor Properties

Development

Development situations and scenarios

Partial semantics (examples)

(F2)

(F3)

Sensory channel

(F4)

Training & testing

Sensory data

Concept

Data labeling

Model class selection, training & testing

Trained Model

Operation

Operational situations and scenarios

Resulting perception

Sensory channel

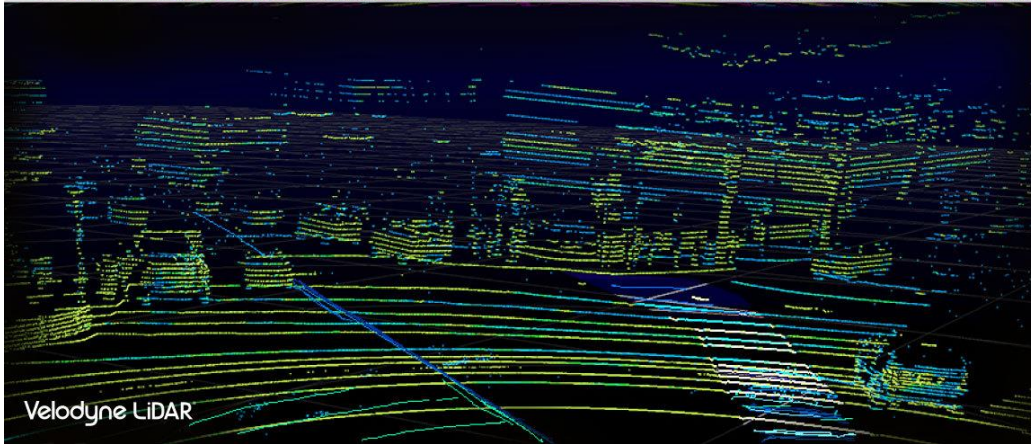
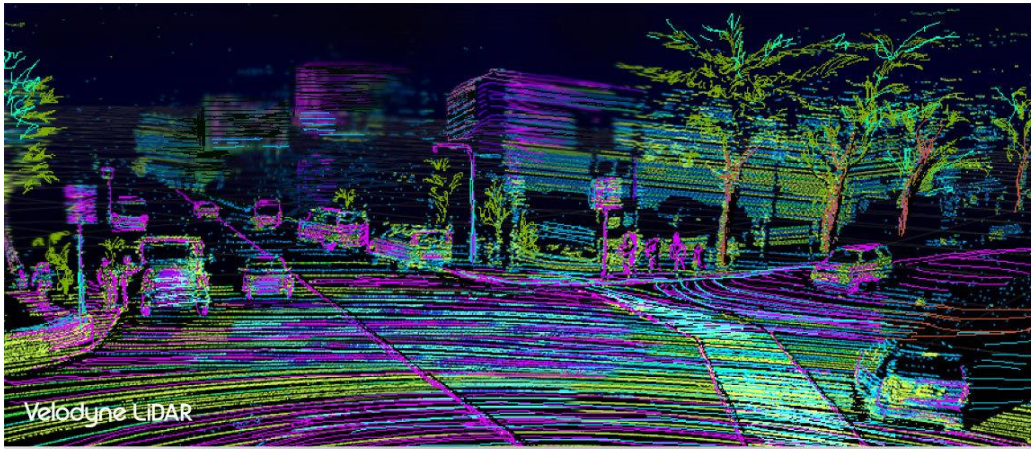
Inference

Concept

Inferred state

Sensory data

F4: Sensor Properties



Daylight White Balance

Cloudy White Balance



Shade White Balance

Tungsten White Balance

F5: Label Uncertainty

Development

Development situations and scenarios

Partial semantics (examples)

(F2)

(F3)

Sensory channel

(F4)

Training & testing

Sensory data

Concept

Data labeling

(F5)

Model class selection, training & testing

Trained Model

Operation

Operational situations and scenarios

Resulting perception

Sensory channel

Inference

Concept

Inferred state

Sensory data

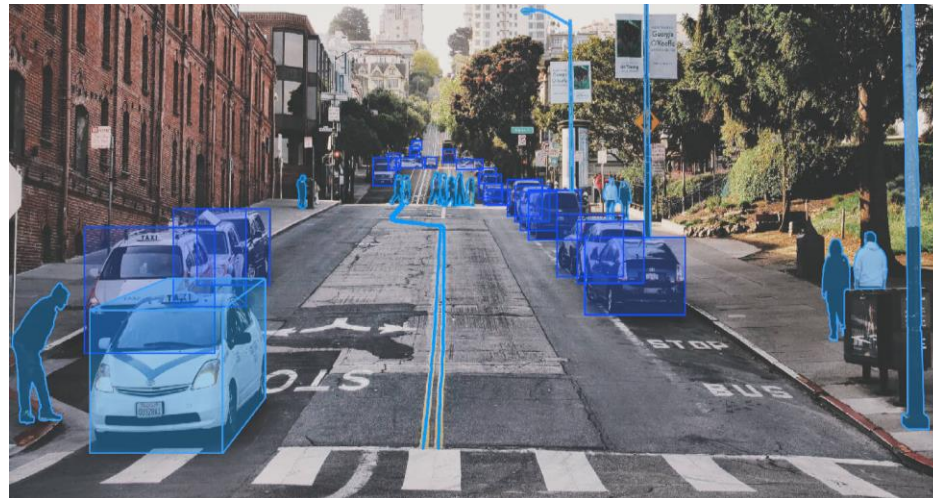
F5: Label Uncertainty



Class: cyclist vs. pedestrian



Bounding box placement uncertainty



3D bounding box placement is challenging

F6: Model Uncertainty

Development

Development situations and scenarios

Partial semantics (examples)

(F2)

(F3)

Sensory channel

(F4)

Training & testing

Sensory data

Concept

Data labeling

(F5)

Model class selection, training & testing

(F6)

Operation

Operational situations and scenarios

Resulting perception

Sensory channel

Inference

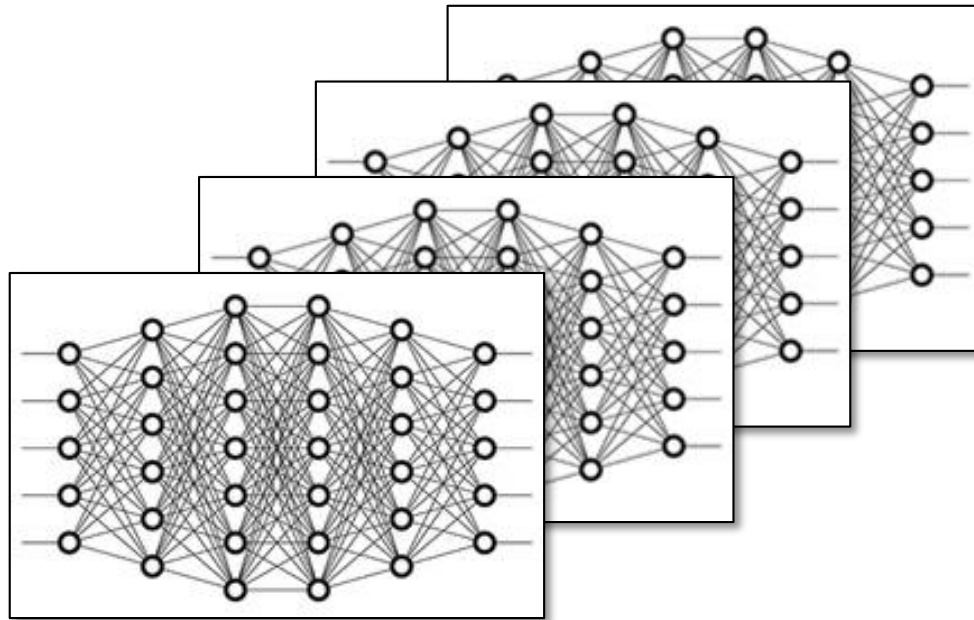
Concept

Inferred state

Sensory data

Trained Model

F6: Model Uncertainty

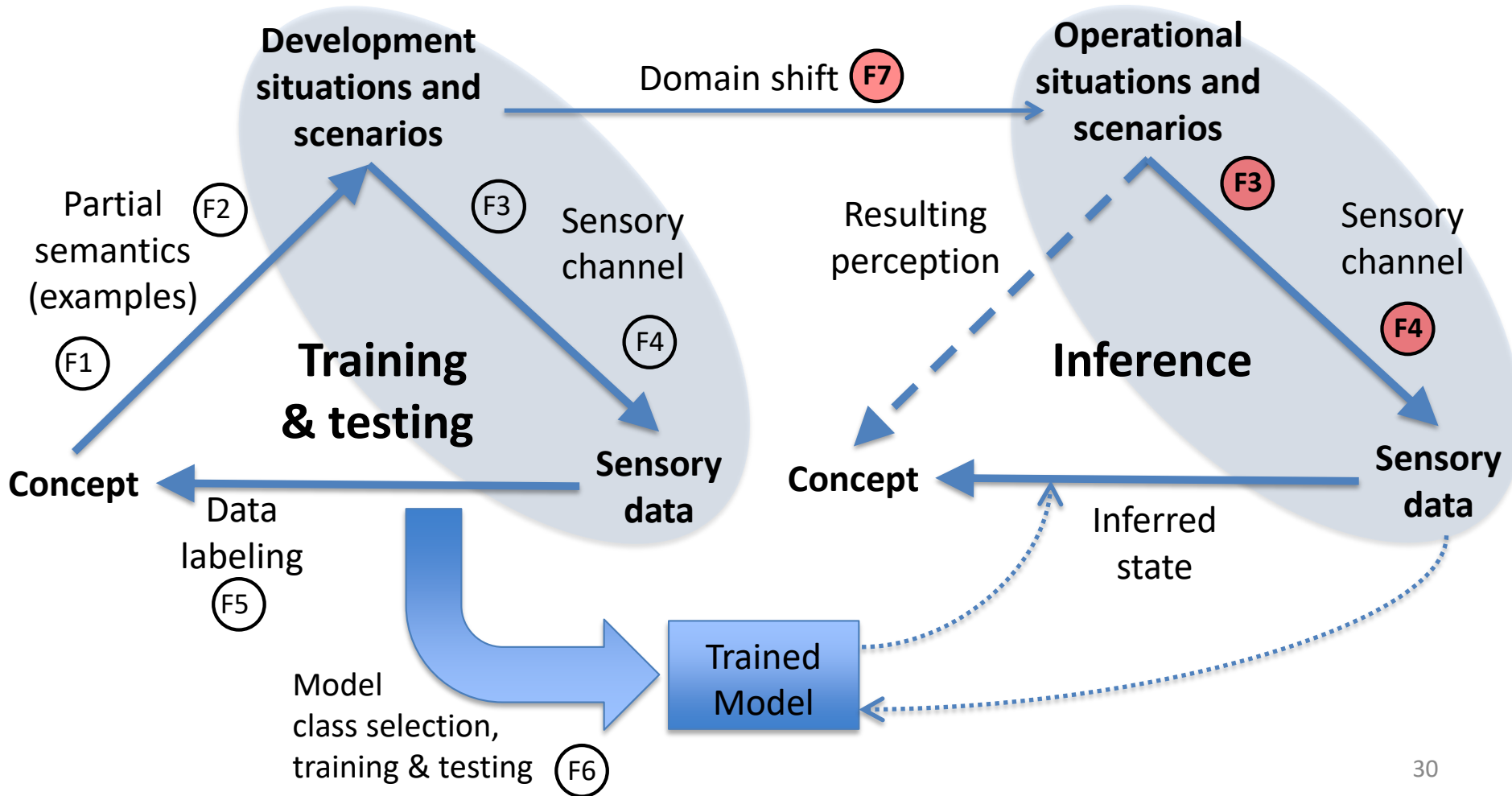


What model was learned in training?
What decisions will it make in operation?

F7: Operational Domain Uncertainty

Development

Operation



F7: Operational Domain Uncertainty



New pedestrian pose



Camera miscalibration



New type of car shape

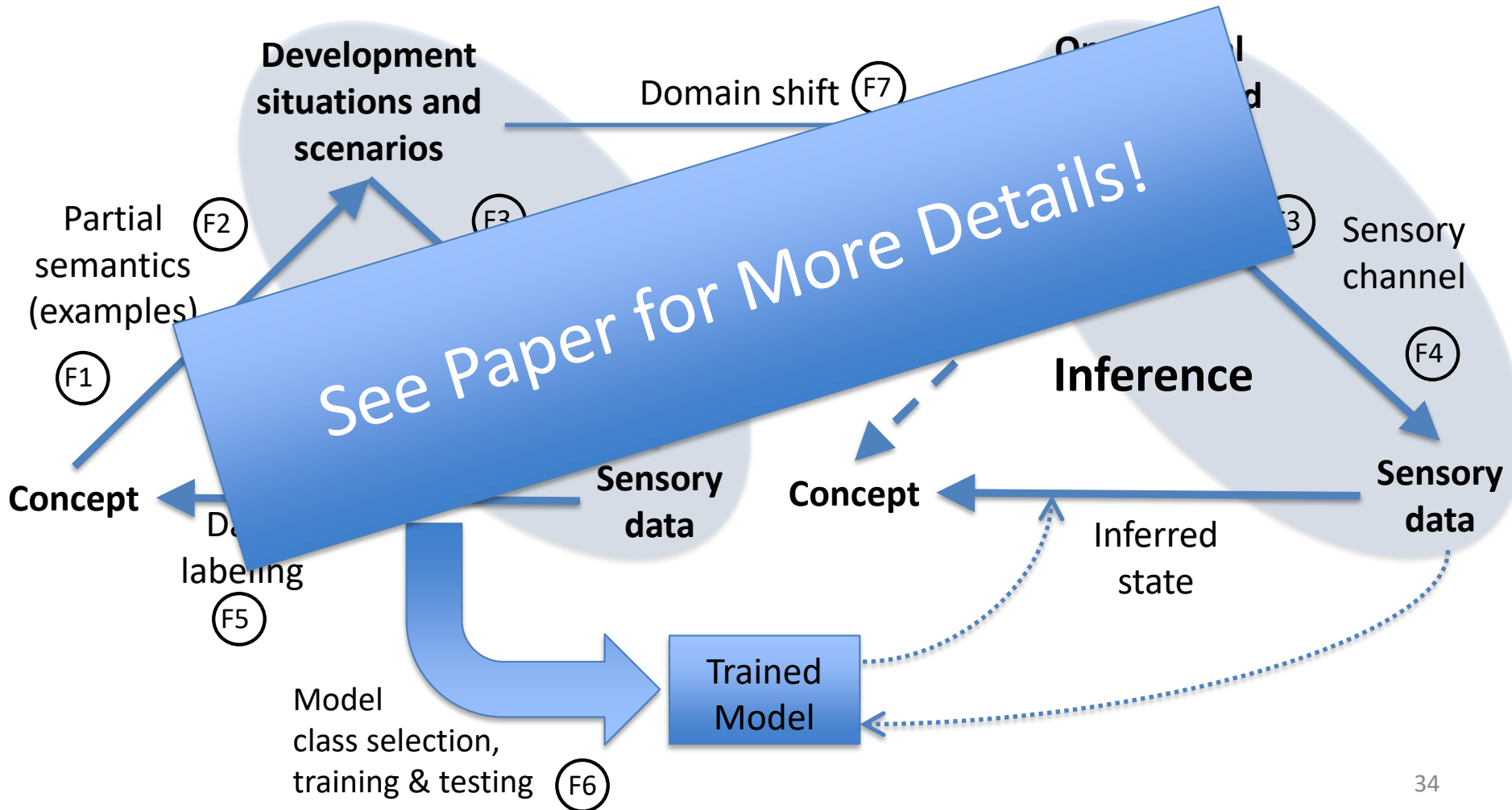


Fly splatters on LIDAR

Factors Influencing Uncertainty

Development

Operation



Conclusion and Next Steps

1. Perceptual uncertainty is a key performance measure in safety requirements
2. Introduced perceptual triangle and identified seven influence factors for perceptual uncertainty when using supervised ML
3. Future: methods to control the influence factors and use them in safety arguments

**Towards a Framework to
Manage Perceptual Uncertainty for
Safe Automated Driving**

Krzysztof Czarnecki & Rick Salay
Waterloo Intelligent Systems Engineering Lab
Electrical and Computer Engineering Department

THANK YOU