34th Annual INCOSE international symposium

hybrid event

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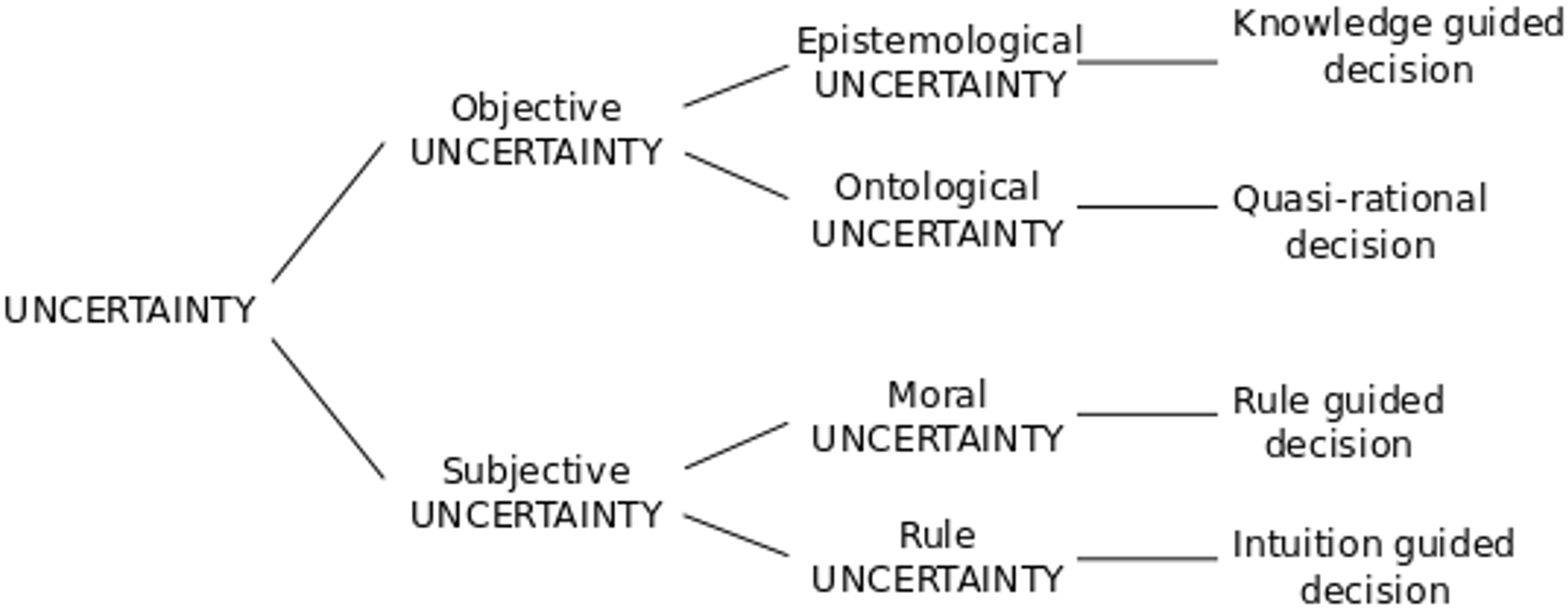
Modeling of Uncertainty in System and Enterprise Models

TOPICS

- The Role of Uncertainty and Precision in Systems Engineering
- Intro to Precise Semantics for Uncertainty Modeling (PSUM)
- Example Modeling Uncertainty with PSUM
- What have We learned About PSUM
- Summary and Way Forward
- Conclusions

THE MANY KINDS OF UNCERTAINTY



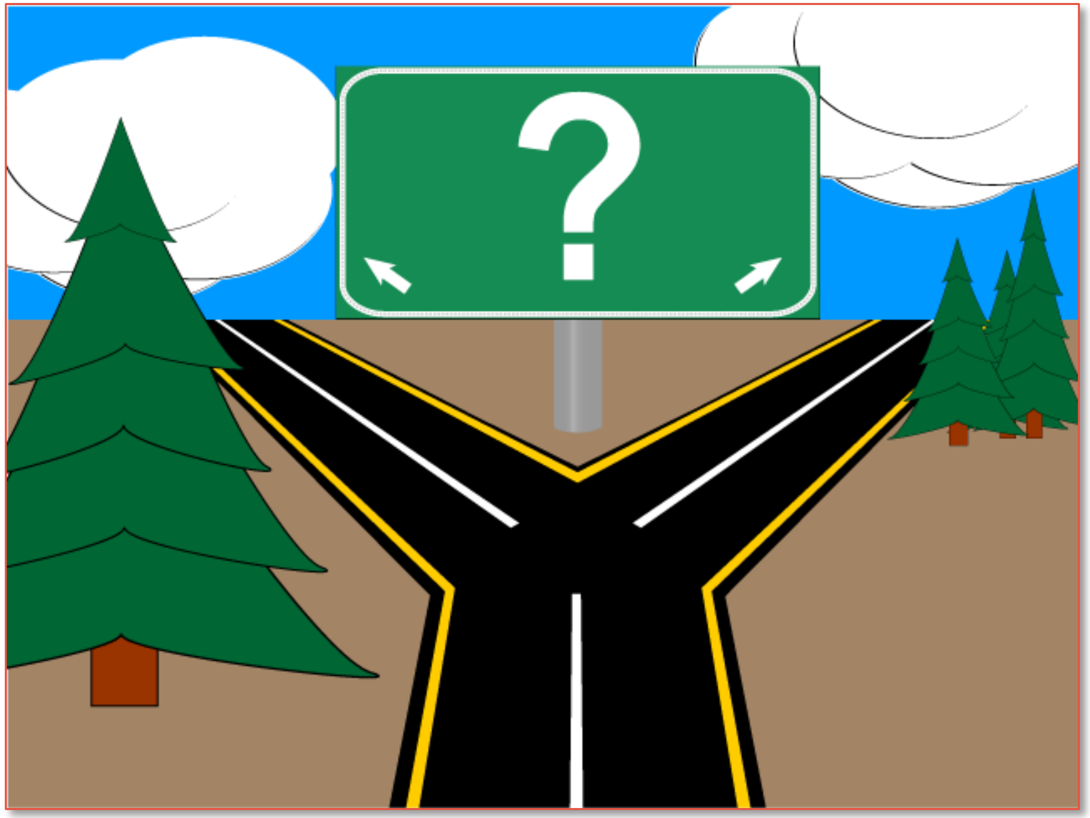
QUESTIONS OF UNCERTAINTY

- ✓ What do we know?
- ✓ What don't we know?
- ✓ How reliable is the information about the situation?
- ✓ What is the confidence level in our knowledge?
- ✓ What is the best way to reduce uncertainty?
- ✓ How good are our models versus reality?

How can we operate in a dependable, safe and secure manner?

WHY MODEL UNCERTAINTY?

- Assurance that our systems will operate in a dependable, safe and secure manner
- Solutions and external factors contribute to operational uncertainty
  - Models of the world versus reality
  - Weather and other environmental effects
  - Accuracy and precision of sensory inputs
  - Human operator interactions and errors
- Reduce development risks caused by uncertainty



***WHEN YOU COME TO A FORK IN THE ROAD, TAKE IT!* – YOGI BERRA**

The Goal: *Eliminate or reduce uncertainty in our system solutions*

WHAT NEEDS TO BE MODELED?

The World is Full of Beliefs and Associated Uncertainties

- What are the consequences of uncertainty?
- What are the sources of uncertainty?
- What is the range of certainty?
- What do you believe and why?
- What is the evidence for this belief?
- How to measure uncertainty of beliefs?
- How much does certainty change over time?

Challenge**: How can we **model uncertainty** with a **standard method?

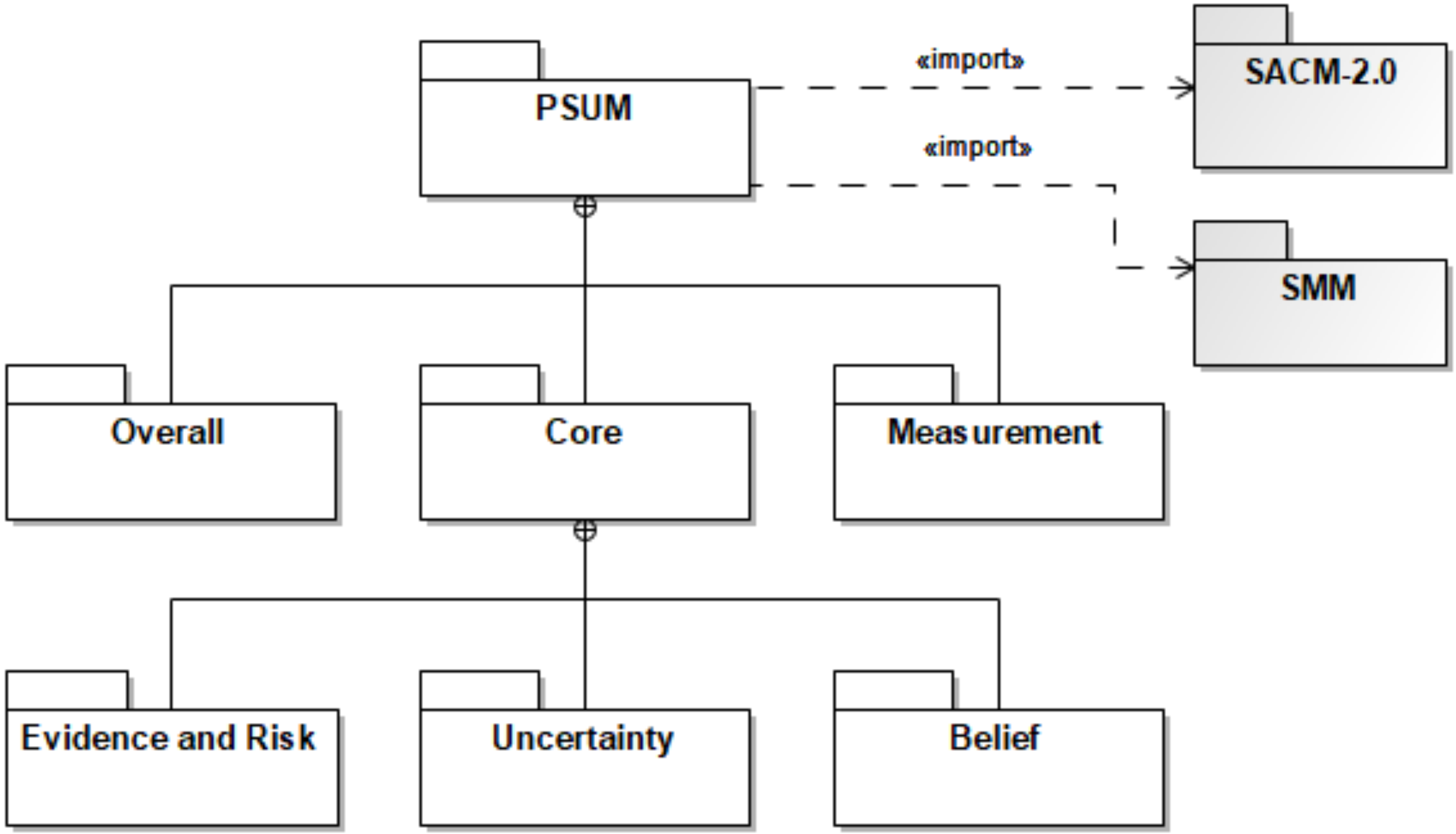
INTRODUCTION TO PRECISE SEMANTICS FOR UNCERTAINTY MODELING (PSUM)

PSUM – DEFINES A METAMODEL FOR UNCERTAINTY

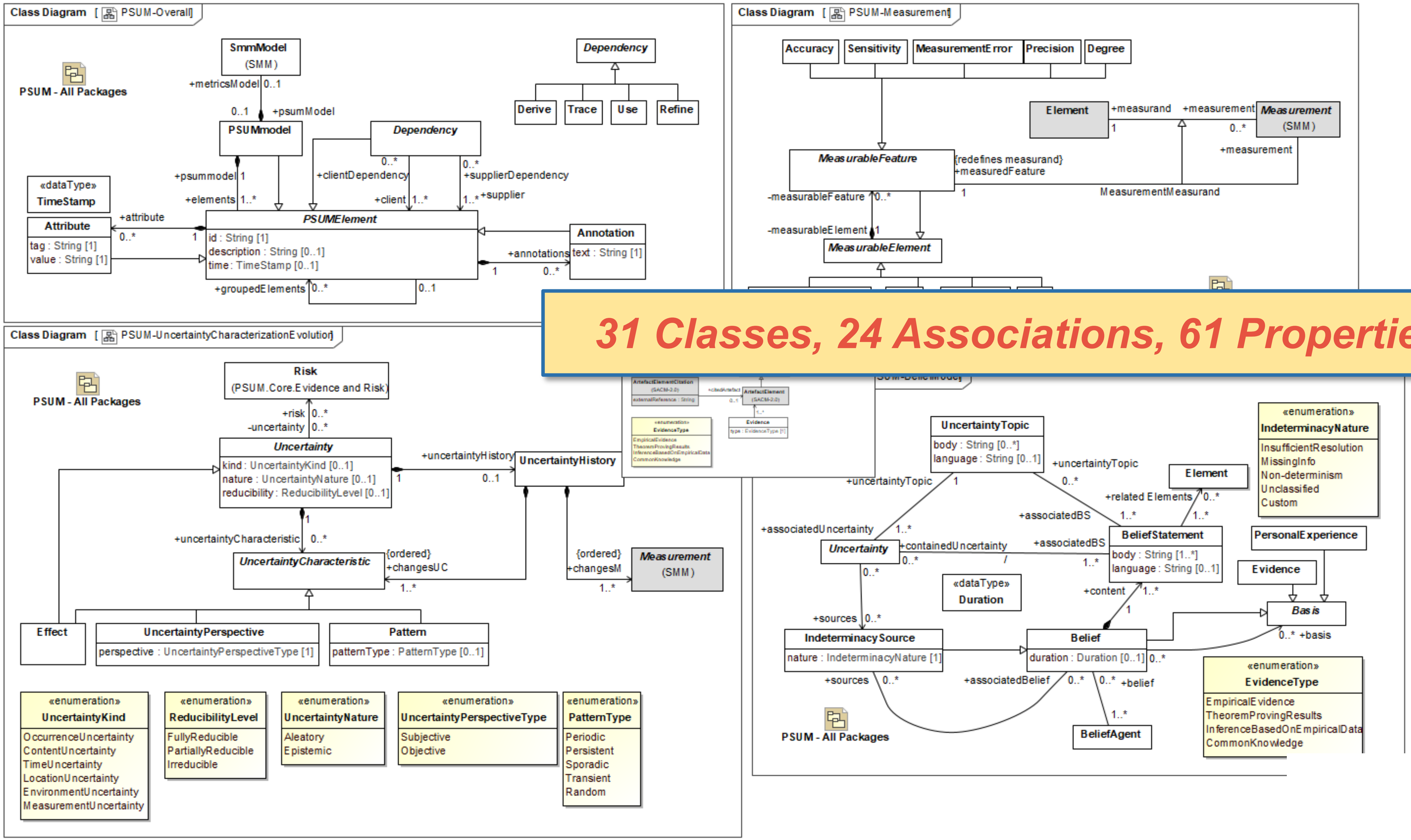
- **Precise Semantics for Uncertainty Modeling (PSUM)** 1.0 beta [OMG Standard]
  - ✓ Foundation for the modeling of uncertainty and the improvement of modeling tools
  - ✓ Modeling of beliefs and sources of beliefs, plus uncertainty and evidence
  - ✓ Enables measurements of uncertainty and uncertainty-related concepts

- PSUM incorporates two other standards
  1. **Structured Metrics Metamodel (SMM)** v1.2 [OMG Standard]
     - ✓ Meta-model for representing measurement information
     - ✓ Used by PSUM for precise semantics related to measures related to uncertainty
  2. **Structured Assurance Case Metamodel (SACM)** v2.2 [OMG Standard]
     - ✓ A set of auditable claims, arguments, and evidence supporting the claim product/service will satisfy its requirements
     - ✓ Structured arguments, evidence, controlled vocabulary, history, motivation, and rationale
     - ✓ Used by PSUM for precise statements and references including evidence to support beliefs

THE PSUM PACKAGE STRUCTURE

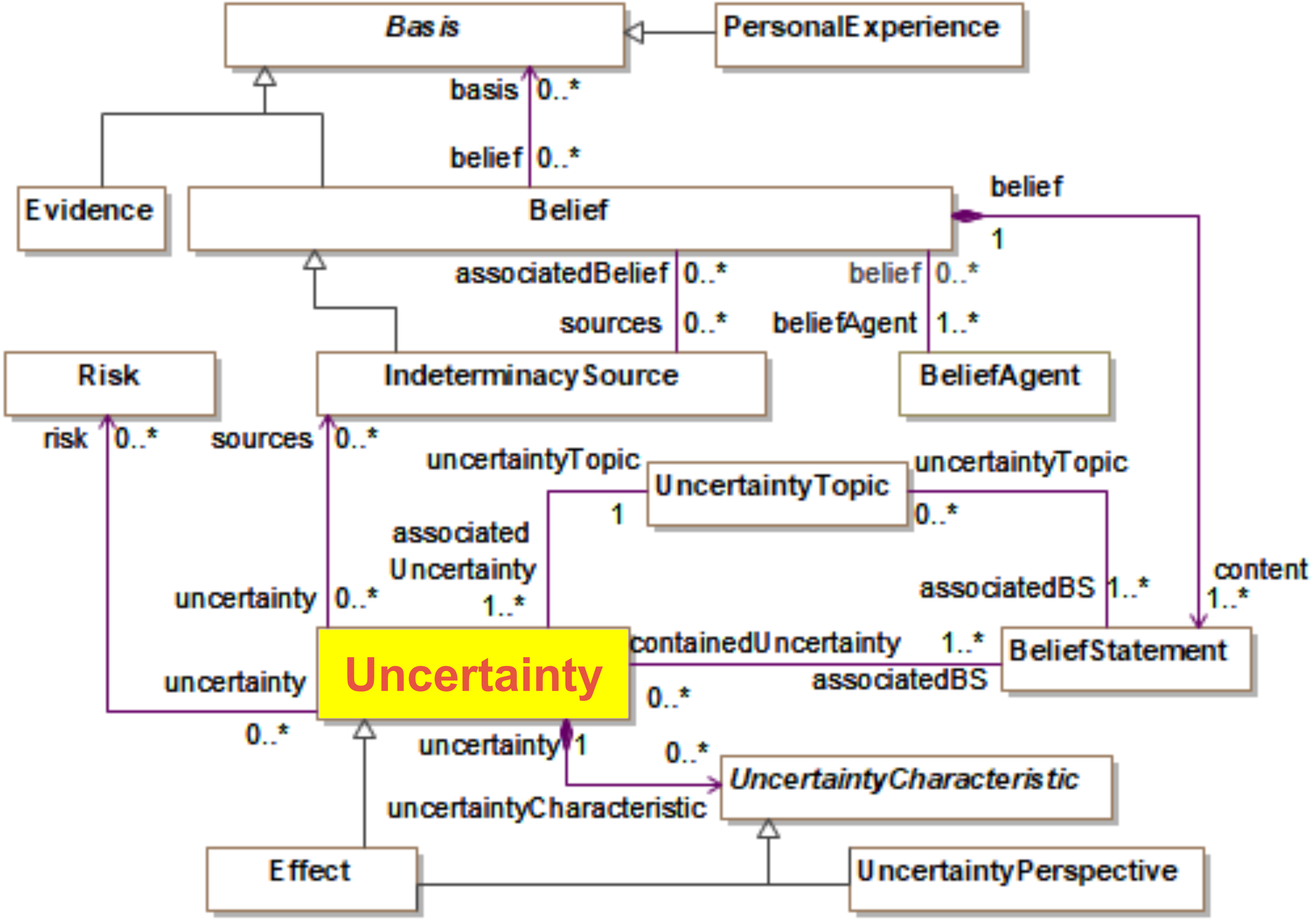


The PSUM standard is non-trivial !!



31 Classes, 24 Associations, 61 Properties

CORE ELEMENTS IN THE PSUM METAMODEL



EXAMPLE OF MODELING UNCERTAINTY WITH PSUM

Exploring the uncertainty of Adaptive Cruise Control operations

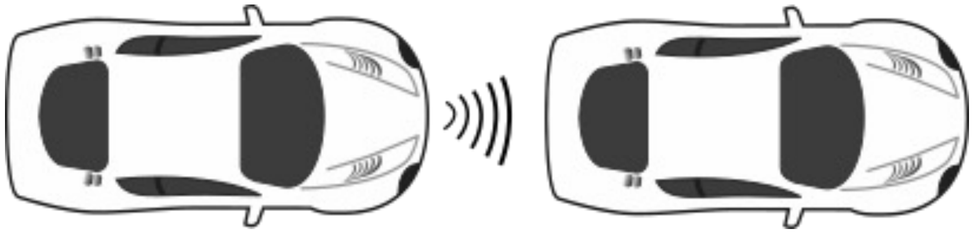
WHAT ARE WE DOING WITH THE PSUM STANDARD?

- Create an example for a PSUM a “test drive”
  - Understand the standard and dependencies
  - Create a recognizable example
  - Analyze usefulness and way forward for MBSE

- This presentation:
  - Overview of the problem of uncertainty and its value to MBSE
  - PSUM overview (metamodel concepts, relations and properties)
  - Example use case and model
  - Future work

USING ADAPTIVE CRUISE CONTROL AS A TEST CASE FOR PSUM

Testing this approach on a real-world problem…



- **Case Study:** Adaptive Cruise Control
- What is Adaptive cruise control?
  - Maintained a set maximum speed **OR** at speed of vehicle ahead
  - Radar and/or cameras used to detect and calculate vehicles ahead
  - Complex algorithms and/or Artificial Intelligence techniques
- Why do you want Adaptive Cruise Control?
  - Controls and adapts speed to flow of traffic
  - Reduces driver workload (and frustration) required to maintain speed in traffic
  - Reduces collisions by automatically reducing speed when traffic slows
  - Faster response to changing traffic speeds

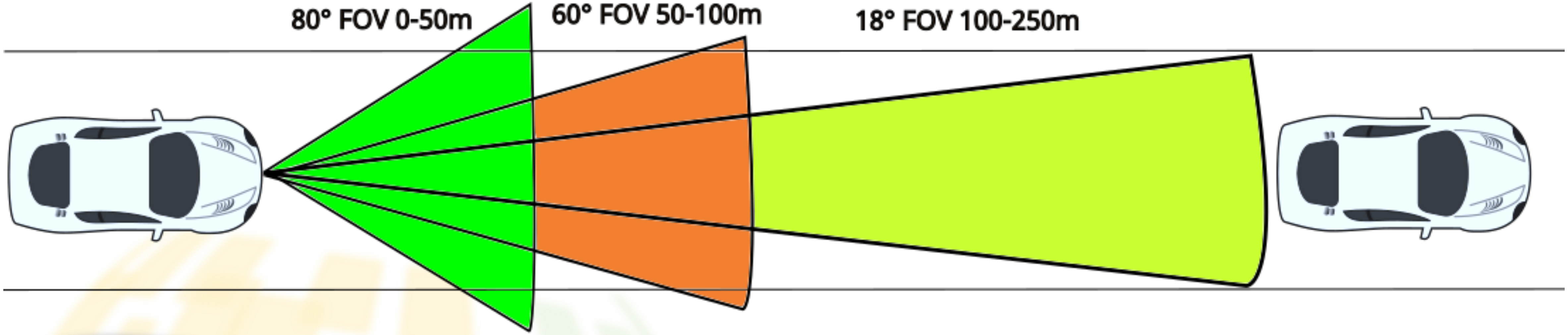
BELIEFS OF THE SYSTEM

What are the “beliefs” that are associated with system operations?

- Algorithms
  - Basis for what the system should “believe”
  - Ensures system operations is safe, secure & dependable
- Sensor Parameters
  - Operational range
  - Precision (+/- range of precision)
  - Noise (relative to the “signal”)
- Poor environment and other conditions will increase uncertainty:

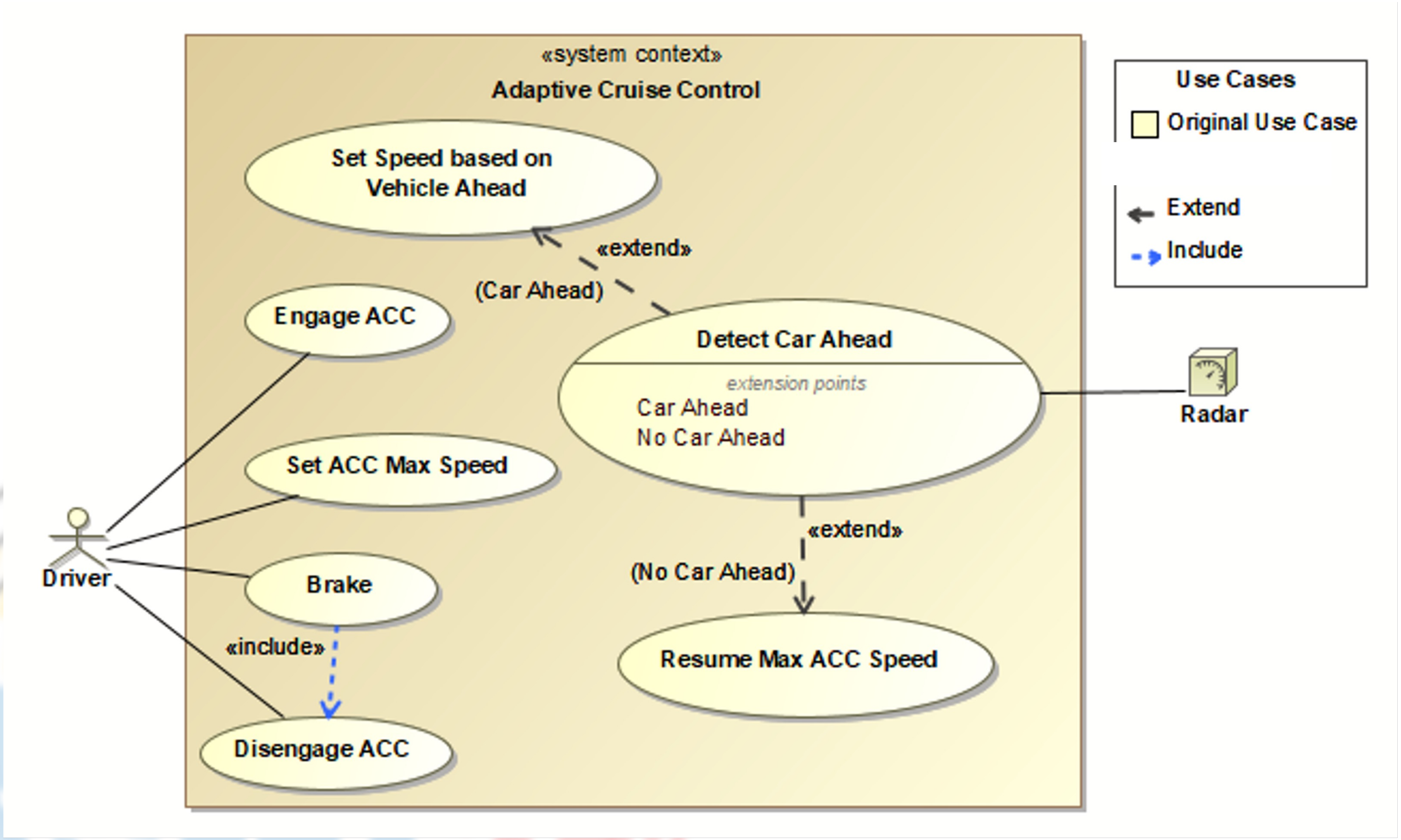
- **Dirt/damage**
- **Rain/snow/fog**
- **Maintenance deficiencies**
- **Target variance (complexity, non-deterministic)**
- **Age of the system**
- **Incorrect operation**
- **Incorrect installation**
- **Unexpected events (out of band, unplanned)**

FIELD OF VIEW (FOV) AND RANGE OF RADAR

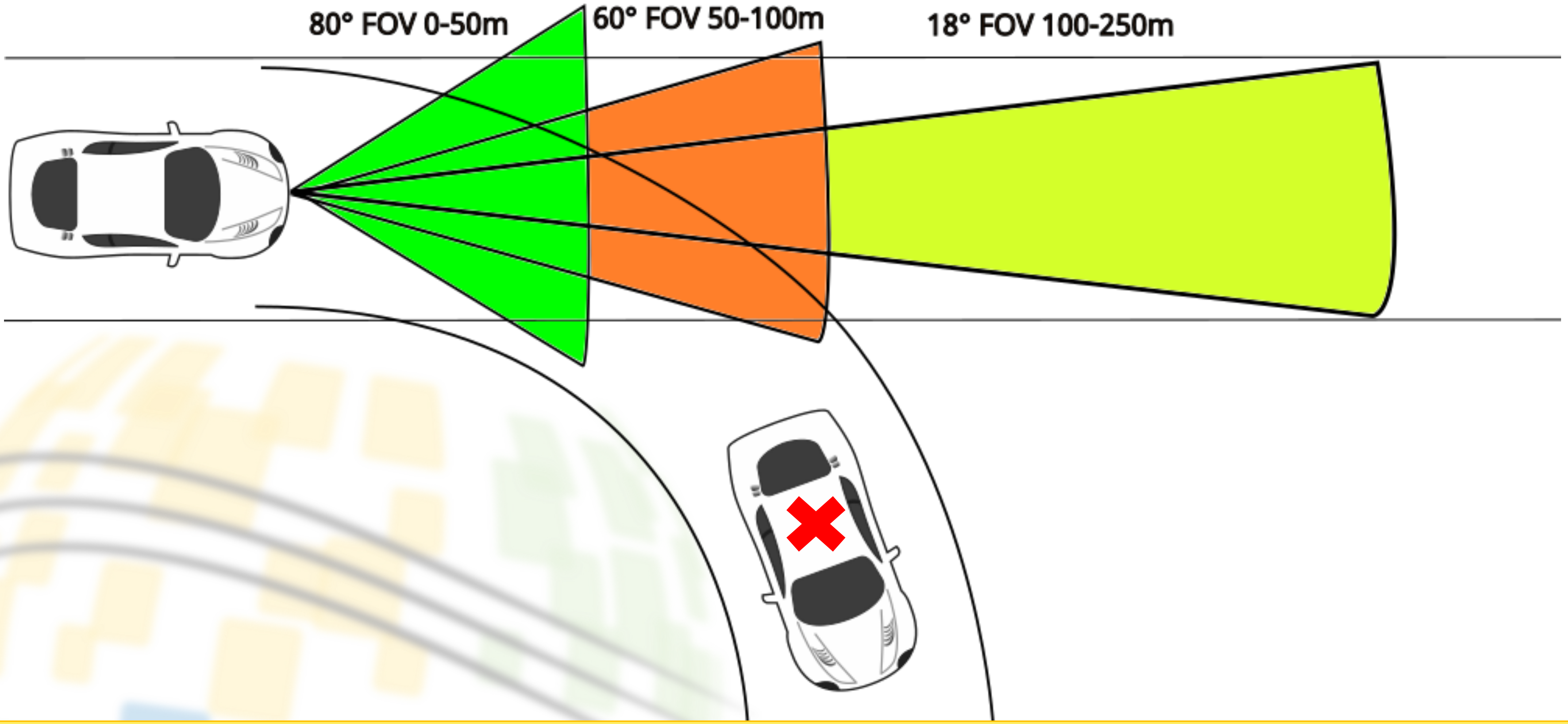


Note that the FOV of the sensor is affected by the Range

TYPICAL USE CASES FOR AN ADAPTIVE CRUISE CONTROL

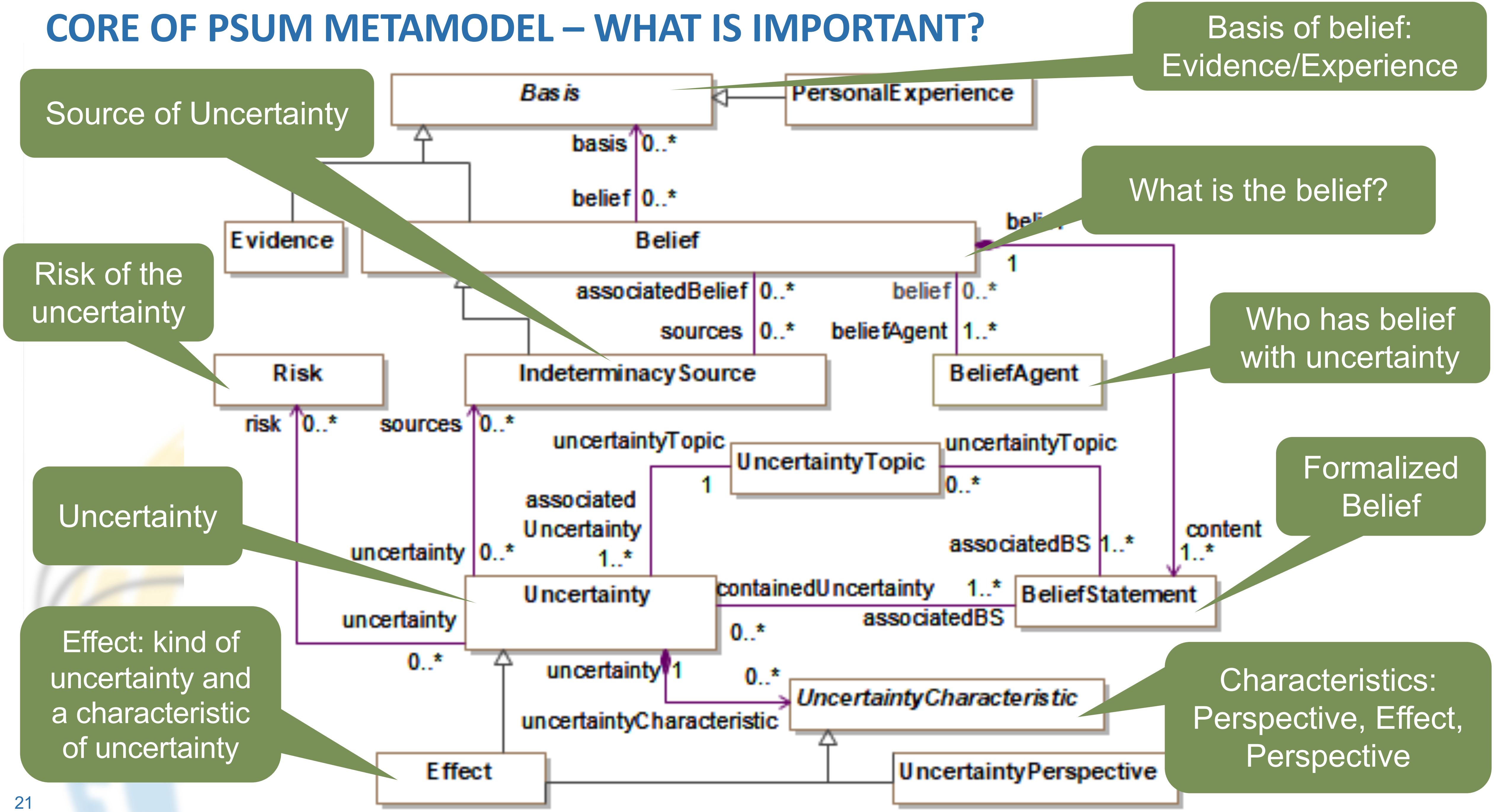


FIELD OF VIEW MEETS A CURVE

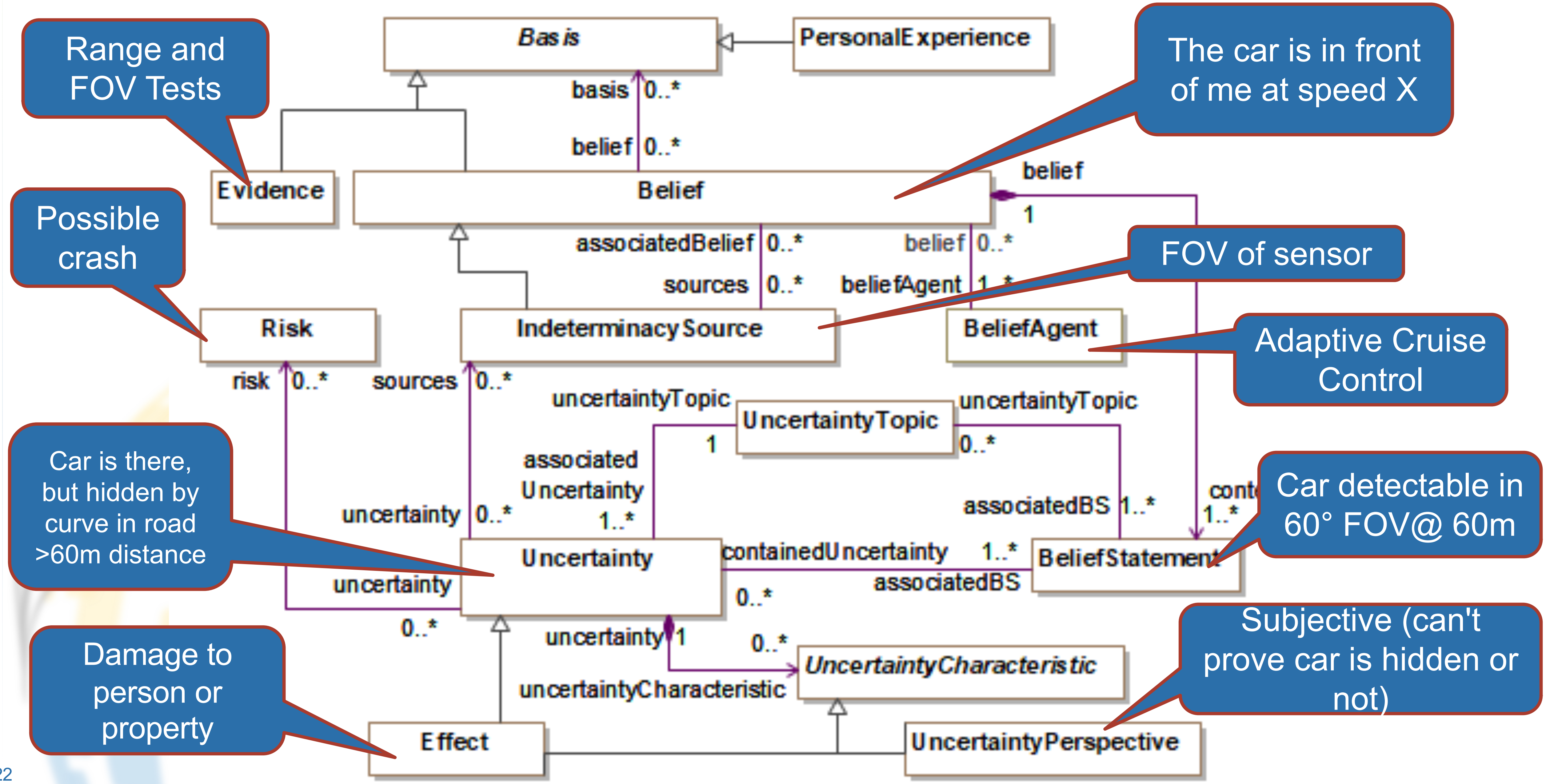


Loss of Signal because of curve and the FOV of sensor

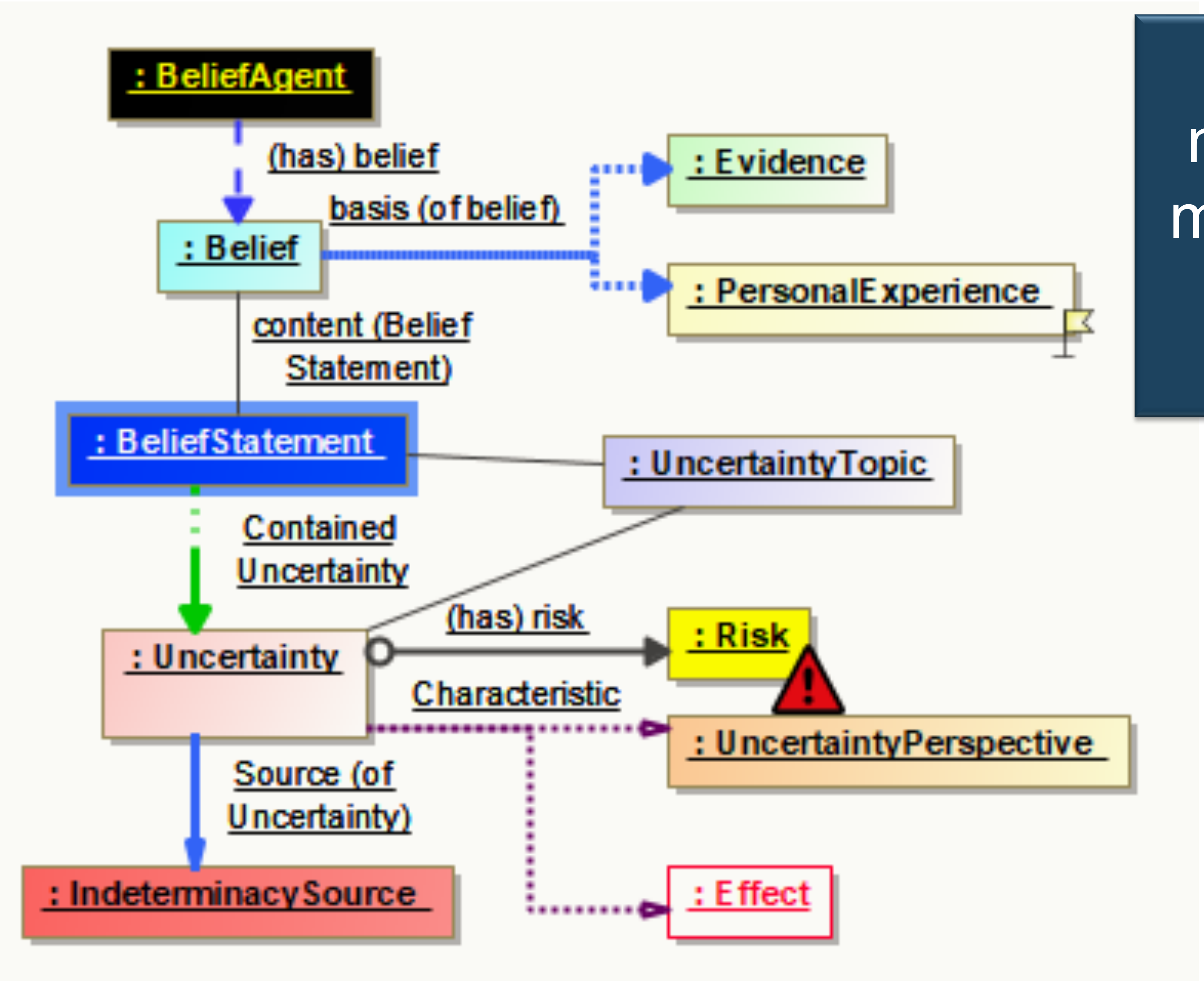
CORE OF PSUM METAMODEL – WHAT IS IMPORTANT?



CORE OF PSUM METAMODEL - EXAMPLES

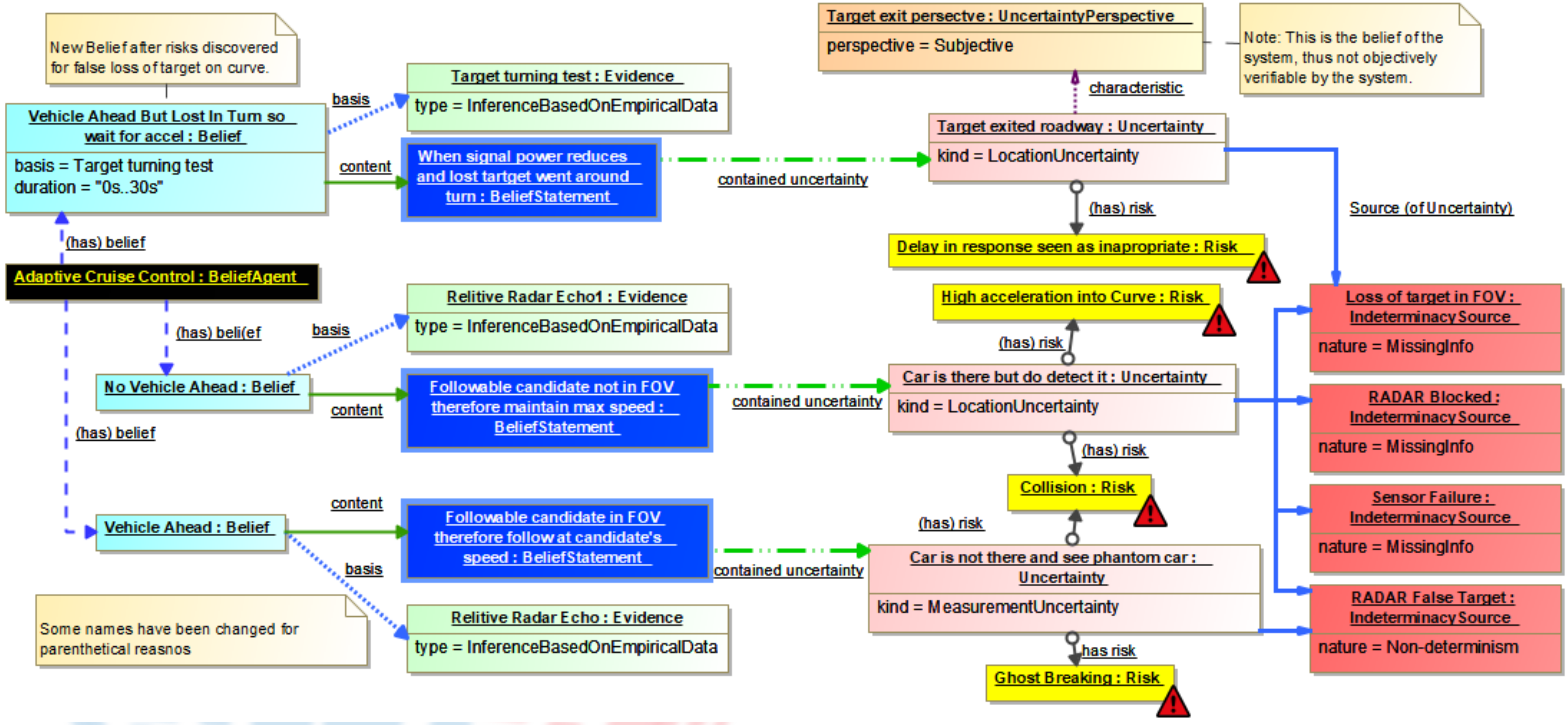


INSTANCE MODEL OF CORE PSUM METAMODEL

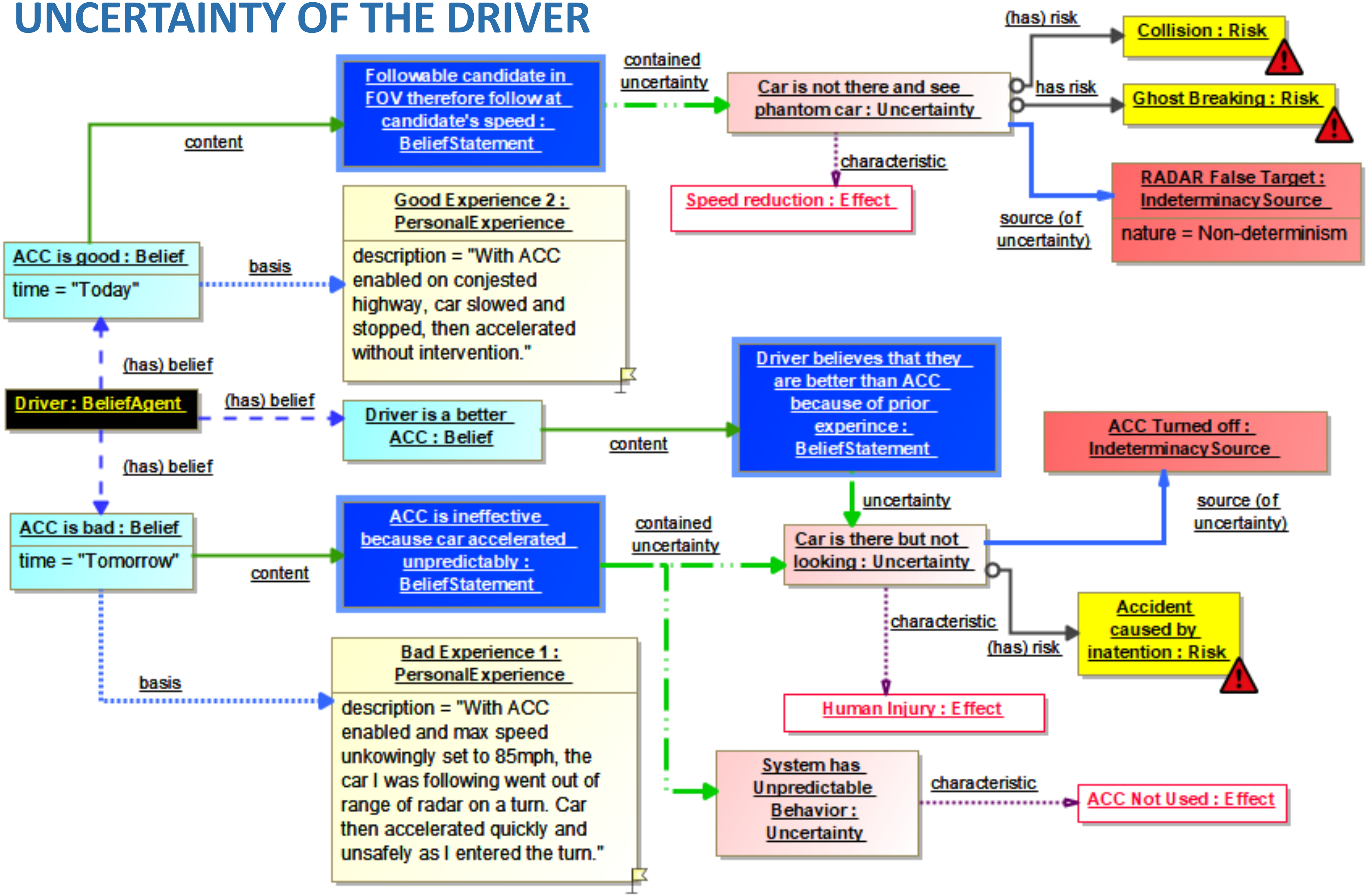


Instance model is the manifestation of the metamodel

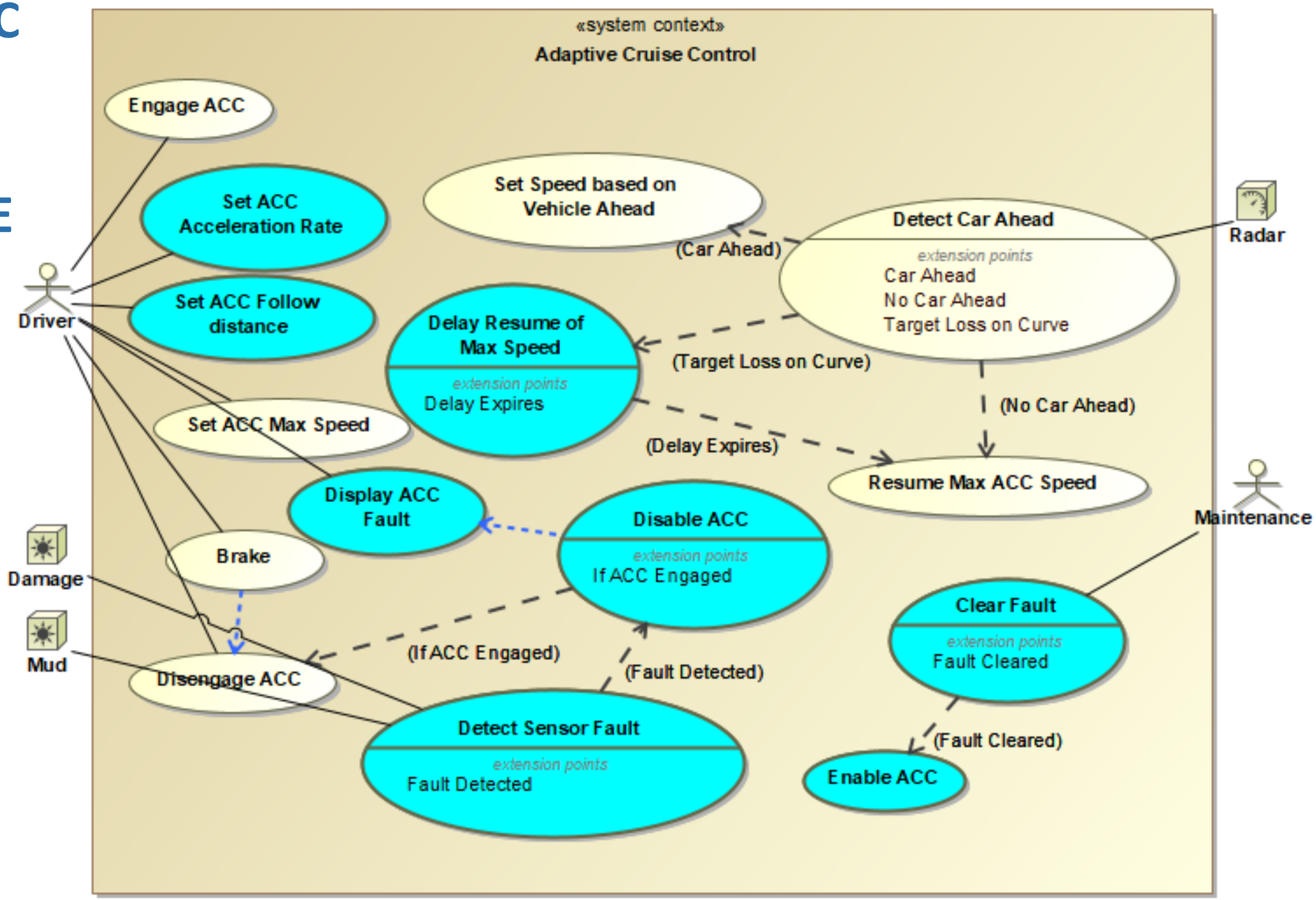
UNCERTAINTY OF ADAPTIVE CRUISE CONTROL SYSTEM



UNCERTAINTY OF THE DRIVER



EXPANSION OF THE BASIC USE CASE WHERE UNCERTAINTY IS CONSIDERED (USING THE PSUM STANDARD)

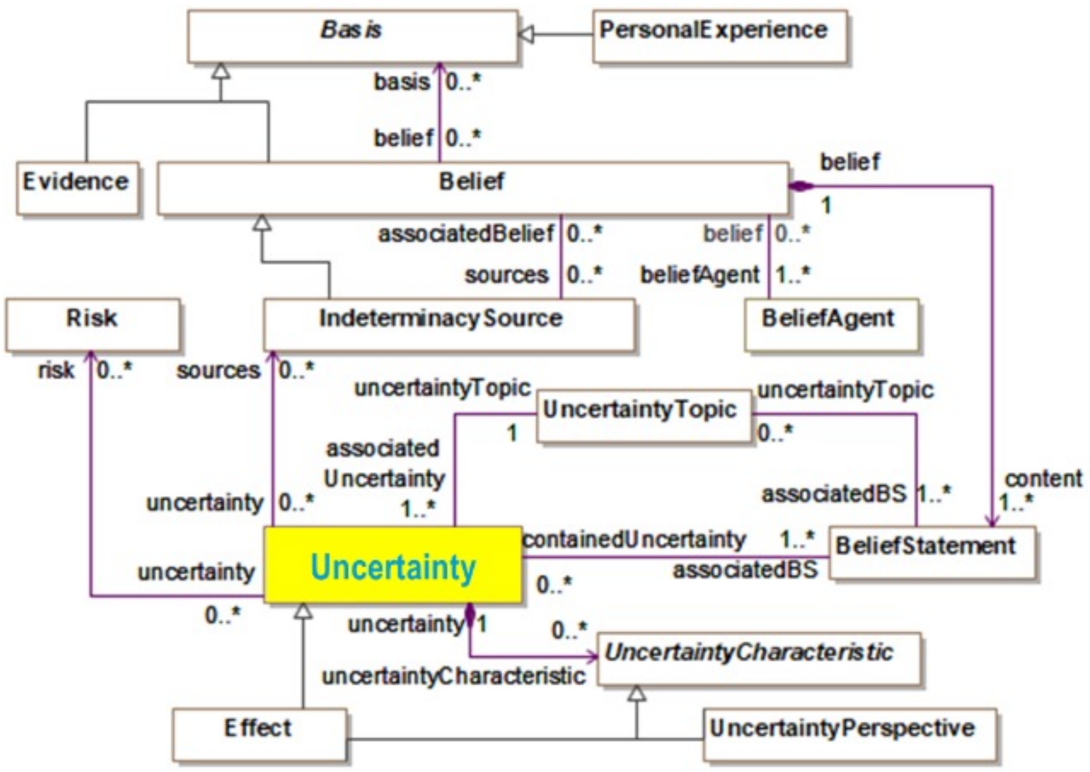


What Does the Use Case Analysis Teach US?

- ✓ Uncertainties in both the system and the vehicle operator can be identified and addressed successfully using PSUM method
- ✓ A small amount of uncertainty analysis can lead to large changes in the design
- ✓ More can be learned by expanding the use case further into the logical & physical design

REDUCING THE SCOPE OF PSUM/SMM/SACM

Reducing the complexity of Architecture Modeling



- The totality of PSUM is huge
  - Reduce scope to allow for useful assertions in the Operational domain
  - Allow for expansion in SE domain as designs evolve
  - Cover key points of precision and uncertainty
- Questions for consideration:
  - Knowing where Concept of Operations is uncertain
  - Understanding the precision of elements to be built in SE
- Other considerations
  - Emergent technology and uncertainty
  - Lack of domain experience

WHAT HAVE WE LEARNED ABOUT THE PSUM STANDARD?

- PSUM as a standard is large and complex
  - At first, the standard is very unclear, but understanding is coming over time with additional use
  - Dealing with the mathematics of uncertainty is part of what makes it complex
- Complexity of characterizing belief and evidence
  - Yes, it is complex, but it does seem to be accessible using an iterative approach
  - Needs more tool support and first attempts are promising
- Abstract nature of uncertainty makes it hard to comprehend
  - Modeling patterns helped with better understanding with concrete examples
  - Need to also deal with how to model uncertainty over time

- **Conclusion:** PSUM is very promising and deserves more study

CONCLUSIONS

- Modeling of uncertainty in system and enterprise modeling can be done but it is challenging since there is only a metamodel in the PSUM spec
- PSUM needs to be integrated into SysML as a standardized profile
- Modeling Profile needs to be adopted by tool vendors and offered as a standard capability in their tools
- Training needs to be provided for this complex subject

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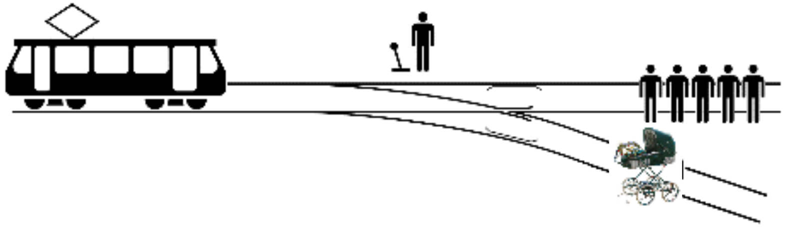
BACKUP SLIDES

CORE CONCEPTS OF THE PSUM STANDARD

Belief Agent	Who or what has a belief	**Uncertainty Topic**	Uncertainty caused by multiple Belief Statements/Uncertainty in combination that cause additional uncertainty
Belief	What is believed by the Agent	**Risk**	Effect of uncertainty on objectives
Belief Statement	Formal expression of the belief	**Uncertainty Characteristics**	Characterizes the associated uncertainty including: Effect, UncertaintyPerspective, and Pattern.
Uncertainty	The state of deficiency of information or knowledge required to understand the content, consequence or likelihood of an UncertaintyTopic existent in a Belief Statement.	**Indeterminacy Source**	Situation where the information required to ascertain the validity of a belief statement is indeterminate in some way, resulting in uncertainty being associated with that statement
Personal Experience	Anecdotal evidence based on isolated examples of someone's personal experience	**Effect**	Effect captures the result of an uncertainty in a belief statement, i.e., the consequence of misinterpreting the belief statement
Evidence	Observation/record of a real-world event occurrence or conclusion of chain of logical inference (truthfulness)		

WHY CONSIDER UNCERTAINTY?



- In ISO 31000 on Risk Management, ***uncertainty*** is defined as “the state, even partial, of deficiency of information related to, understanding or knowledge of an event, its consequence, or likelihood.”
  - In development, there are many unknowns (i.e. uncertainties) associated with proposed design solutions and unknowns regarding the people creating or executing the design
  - In operating systems, there are unknowns due to precision of systems either in capabilities or sensors
  - Algorithms that interpret sensor data may be only estimations of reality (incomplete model and/or sensor limits)
  - Need to deal with various sources of noise from sensors and the environment
  - Subjective uncertainty (rules and morality) lead to uncertainty (legality of operation, trolley problems)

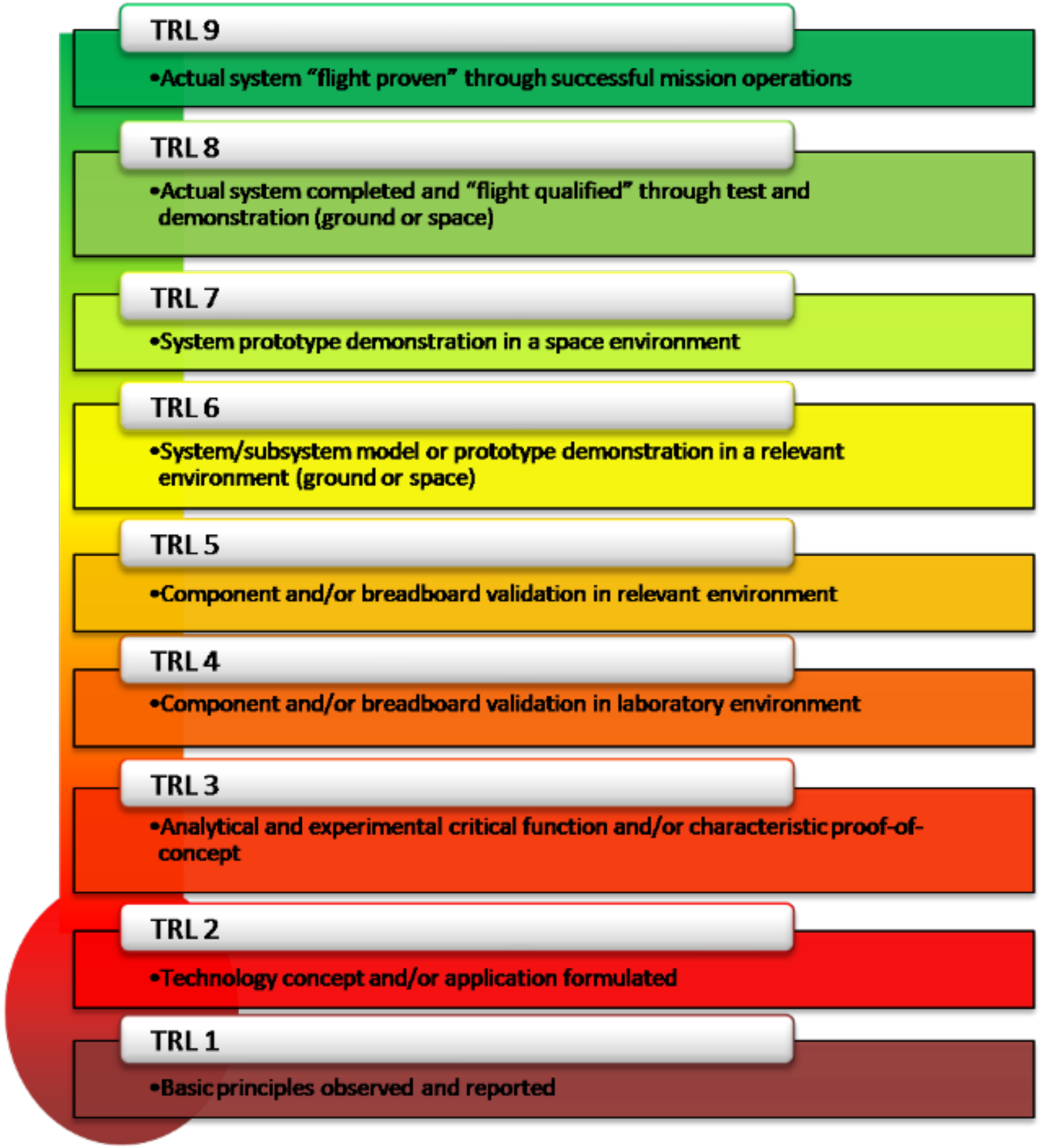
CONSEQUENCES OF UNCERTAINTY

Uncertainty	Consequence
Distractions during driving	Operator error causes accident leading to injury or death
Poor understanding of low temperature on performance	Shuttle O-ring accident causes complete mission failure
Radar controlled cruise control cannot see around curves	Acceleration on curve can lead to accidents (and death!)
One Pedal driving and other new control mechanisms	Hertz had additional operation costs due to damage
Misunderstanding the damage possibility of a foam strike	Shuttle breakup upon reentry

REDUCING EFFECTS OF UNCERTAINTY

When we consider uncertainty, systems can be improved

- **Distracted driving - We know drivers are distracted!**
  - Lane-keeping assist
  - Emergency braking
- **NASA Technology Readiness Levels (TRL) – We know it is new!**
  - Steps to prove science and hardware
  - Shuttle used Magnetic Core memory because it was flight-proven
- **Boats sink – Bernoulli versus the iceberg**
  - Improved lifeboats
  - Passenger/crew emergency training
- **Airplanes crash…**
  - Crash investigations
  - Emergency Airworthiness Directives
- **Spacecraft Navigation errors**
  - Small orbital corrections to larger errors in launch trajectory
  - Landing ellipses cover safe landing within margin of errors
  - Space X Falcon 9's soft landing 18m wide craft within a 52m × 91m target in the ocean!



WHY MODEL BELIEF AND UNCERTAINTY?

Where is the value in knowing what you don't know?

1. New use cases and requirements to control uncertainty
2. A more complete understanding of the design space
3. More complete identification of faults and failures
4. Avoid assumptions, superstitions, & so-called "best" practices that are not backed up by evidence (i.e., assertions without proof)

- Simply:
  - Write down our beliefs (assumptions)
  - Correct beliefs until they are facts with uncertainly
  - Document the bounds of the system's operation and risks

Before you *assume*, try this crazy method called "*asking*"

Modeling Uncertainty

- Who/what (*people/algorithms/sensors*) have a beliefs?
- What are the beliefs?
- What is the range of uncertainty
- How does certainty change over time?
- What are the consequences of uncertainty?
- What is uncertain?
- Characteristics of uncertainty?
- Uncertainty changes due to conditions , technology, failures, etc.?

THE PURPOSE OF PSUM STANDARD

Modeling of belief and uncertainty

- Build the foundation for developing uncertainty modeling solutions
- Guide the implementation of uncertainty modeling tools
- Provide the basis for materials and resources in the application of uncertainty modeling
- Serve as the cornerstone of uncertainty modeling solutions.
- Primary capabilities:
  - Capturing uncertainty and its related concepts
  - Enabling measurements of uncertainty and uncertainty-related concepts.

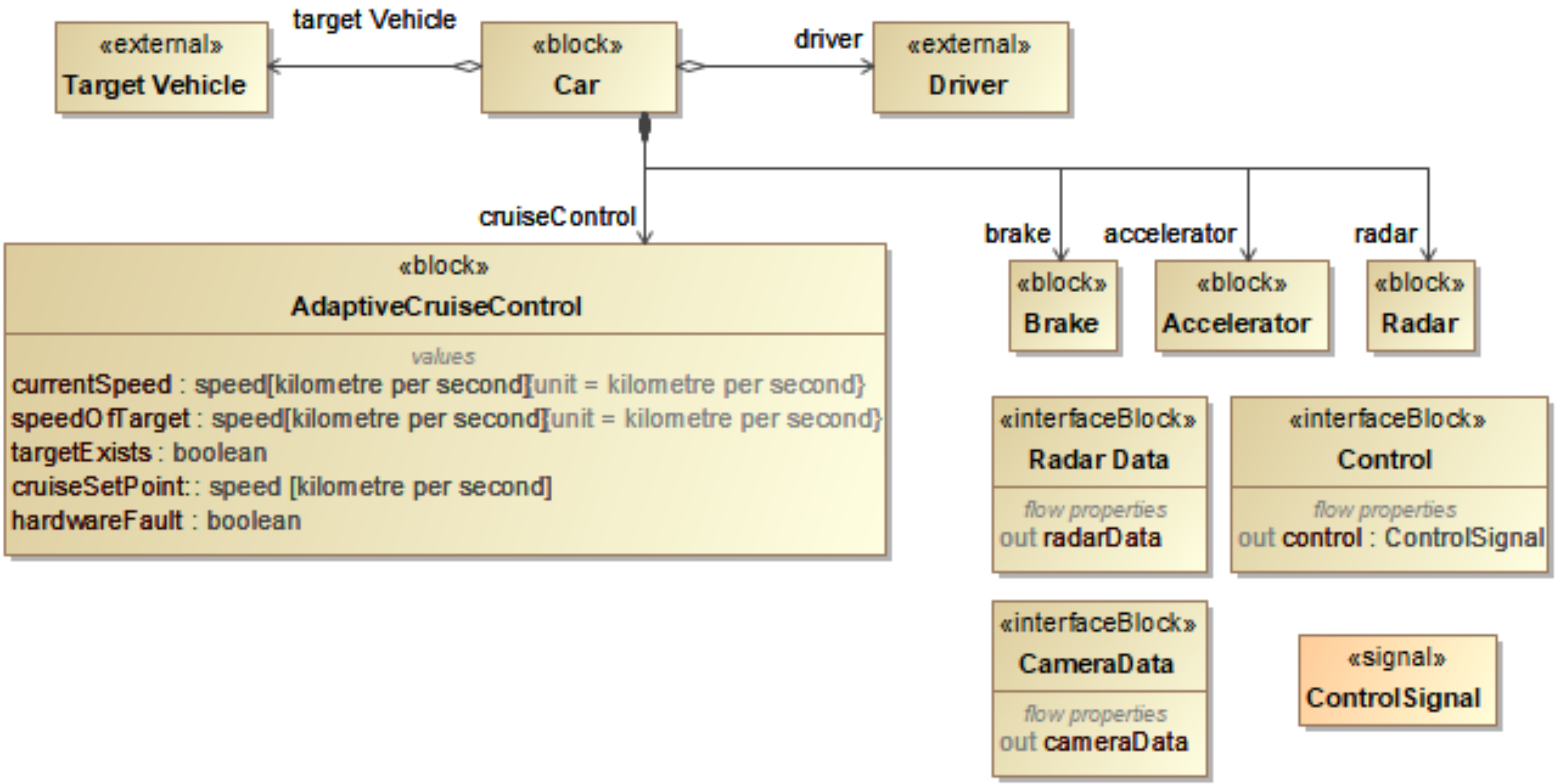
MODELING OF UNCERTAINTY IN SYSTEM AND ENTERPRISE MODELS

- Presenters
  - Daniel Brookshier – Dassault Systems
  - James Martin - Aerospace Corp
- Modelers typically create system models assuming some degree of certainty in what they are describing. However, there is a need to understand how much uncertainty there is in their projections of what the system will do and how well it perform its operations. We will discuss a new standard from OMG called Precise Semantics for Uncertainty Modeling (PSUM) that specifies concepts of uncertainty, accuracy, precision, and related concepts, and we will describe how to PSUM concepts in modeling our systems.
- Uncertainty is integral to the complete understanding of systems
- Uncertainty is integral to the complete understanding of systems
  - Uncertainty/precision of sensors
  - Variance of user operations
  - Algorithmic processing of sensor data and limits to its ability to model reality
  - Uncertainties from failure, noise, environmental effects, maintenance, and age of a system can add to uncertainty of system operations
  - Input to risk management
- Uncertainty is a domain that has not been directly modelable in MBSE
- We will show the new Precise Semantics for Uncertainty Modeling (PSUM) standard from the OMG
- Example of uncertainty in an Adaptive Cruise Control System
- Lessons learned and future of the PSUM standard

POSSIBLY SOURCES OF UNCERTAINTY

- **Design Uncertainty** – Is your model implementable and operate as expected?
- **Sensor Uncertainty** – How good are inputs of the system?
- **Failure Uncertainty** – What are the effects of failures on uncertainty of operation?
- **Operational Uncertainty** – How good is your processing at reflecting the real world and its use?

CAR WITH ACC



«external»
Target Vehicle
target Vehicle
«block»
Car
driver
«external»
Driver
cruiseControl
brake
accelerator
radar
«block»
AdaptiveCruiseControl
values
currentSpeed : speed[kilometre per second]{unit = kilometre per second}
speedOfTarget : speed[kilometre per second]{unit = kilometre per second}
targetExists : boolean
cruiseSetPoint:: speed [kilometre per second]
hardwareFault : boolean
«block»
Brake
«block»
Accelerator
«block»
Radar
«interfaceBlock»
Radar Data
flow properties
out radarData
«interfaceBlock»
Control
flow properties
out control : ControlSignal
«interfaceBlock»
CameraData
flow properties
out cameraData
«signal»
ControlSignal

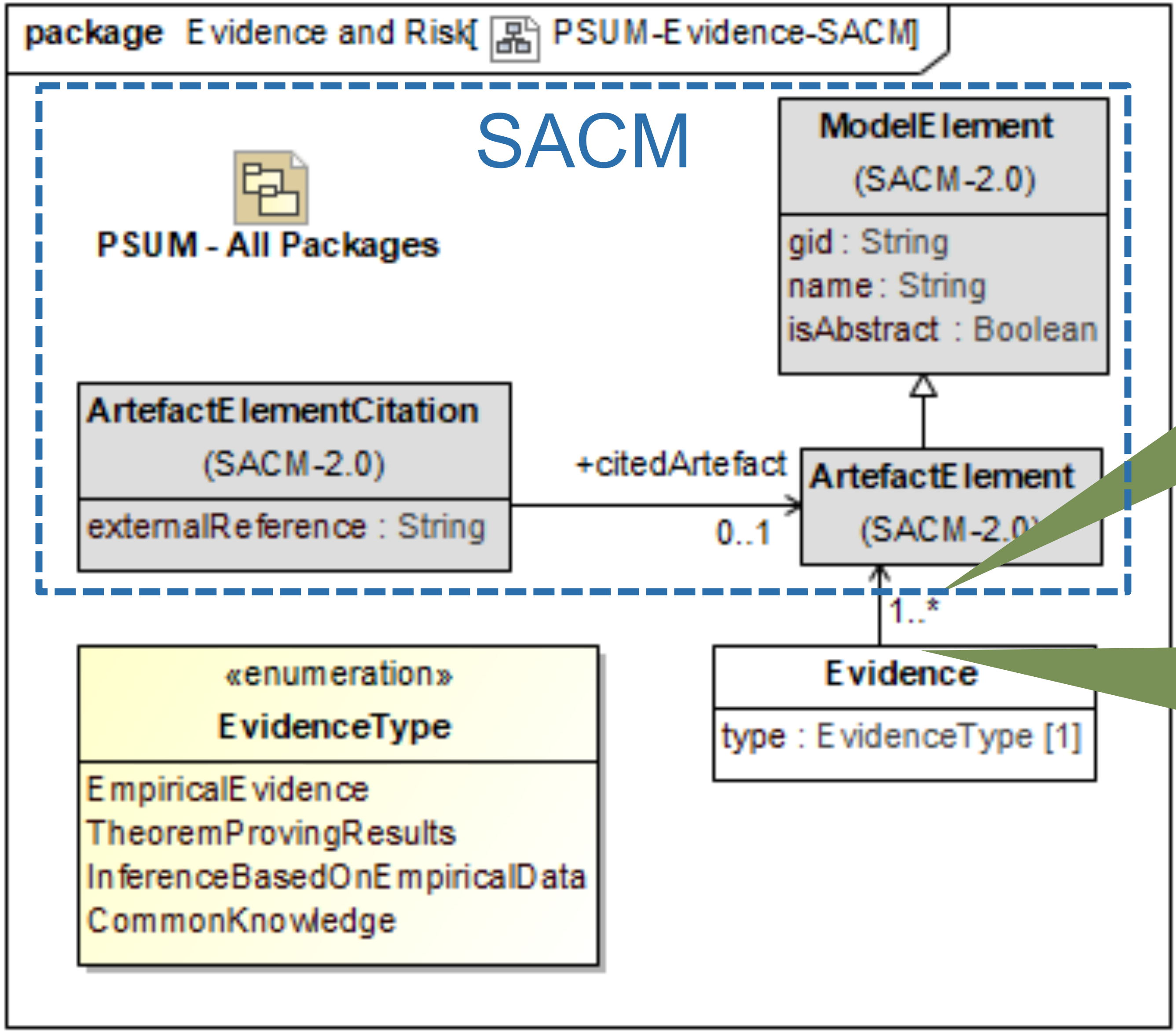
UNCERTAINTY OF ADAPTIVE SYSTEMS

- Uncertainty of a system is generally unavoidable!
- Systems that we build today are meant to adapt to situations and conditions

Environment	Context (including interactions with human actors) in which the system is running (e.g., the uncertainties induced by the behavior of a human-in-the-loop, which is not deterministic).	**Goals**	Goals that the self-adaptive loop uses to manage the system. An example is not fully anticipating changing goals in the future.
Model	Models that the self-adaptive system employs (typically for decision-making). One example might be the abstraction of some aspect of the real system that is not represented in its model, which induces epistemic uncertainty.	**Managed System**	Subsystem being managed by the managing subsystem in the self-adaptive system. An example is uncertainty caused by the complexity of the managed subsystem.
Adaptation Functions	Functionalities that self-adaptive loop performs. An example is the uncertainty caused by faulty sensors of the adaptive system	**Goals**	Components needed by the self-adaptive system to operate. An example is uncertainty from changes in resource availability.

PSUM DETAILS

PSUM METAMODEL: CONCEPTS RELATED TO EVIDENCE

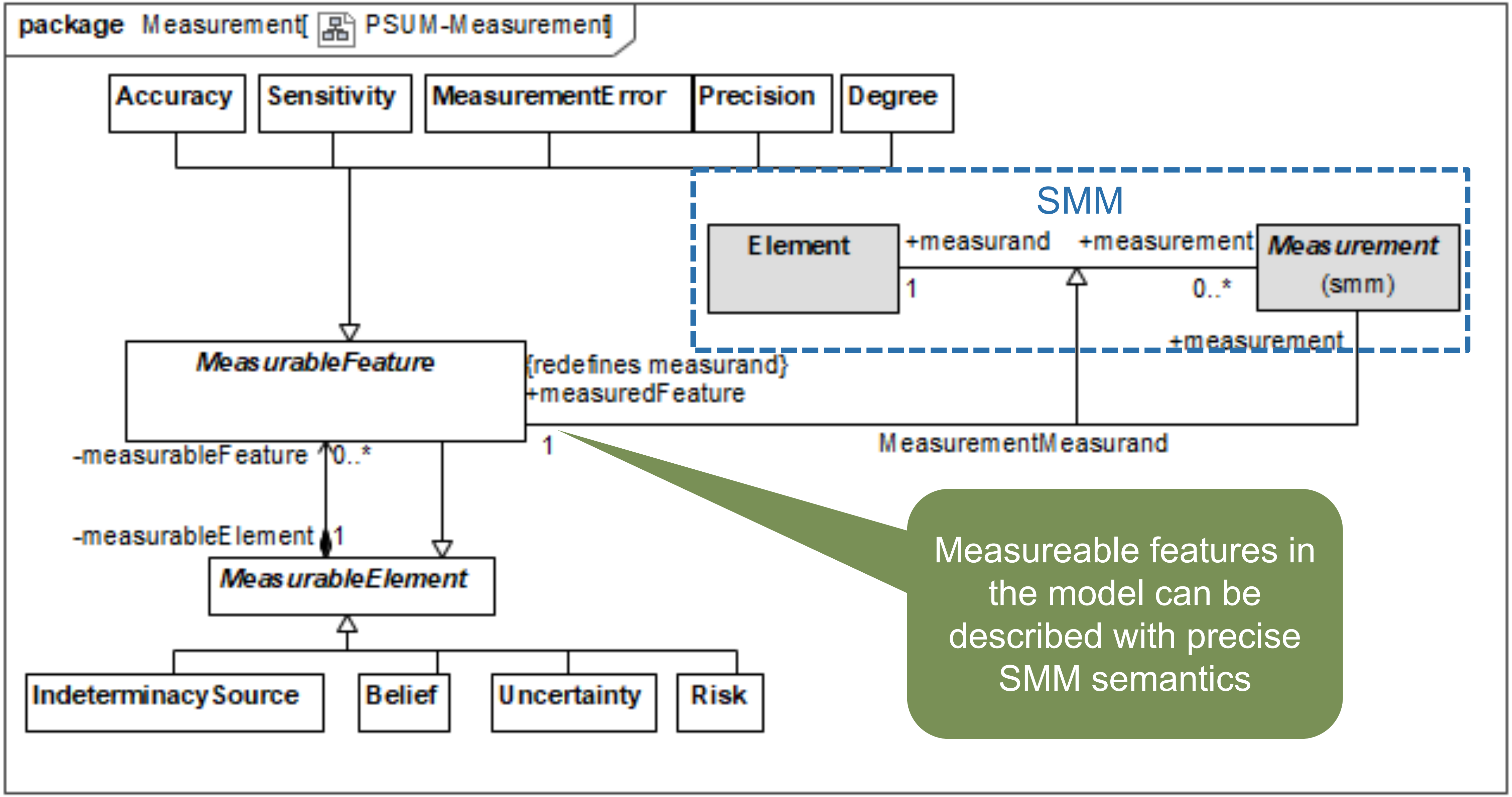


One or more artifacts supporting evidence

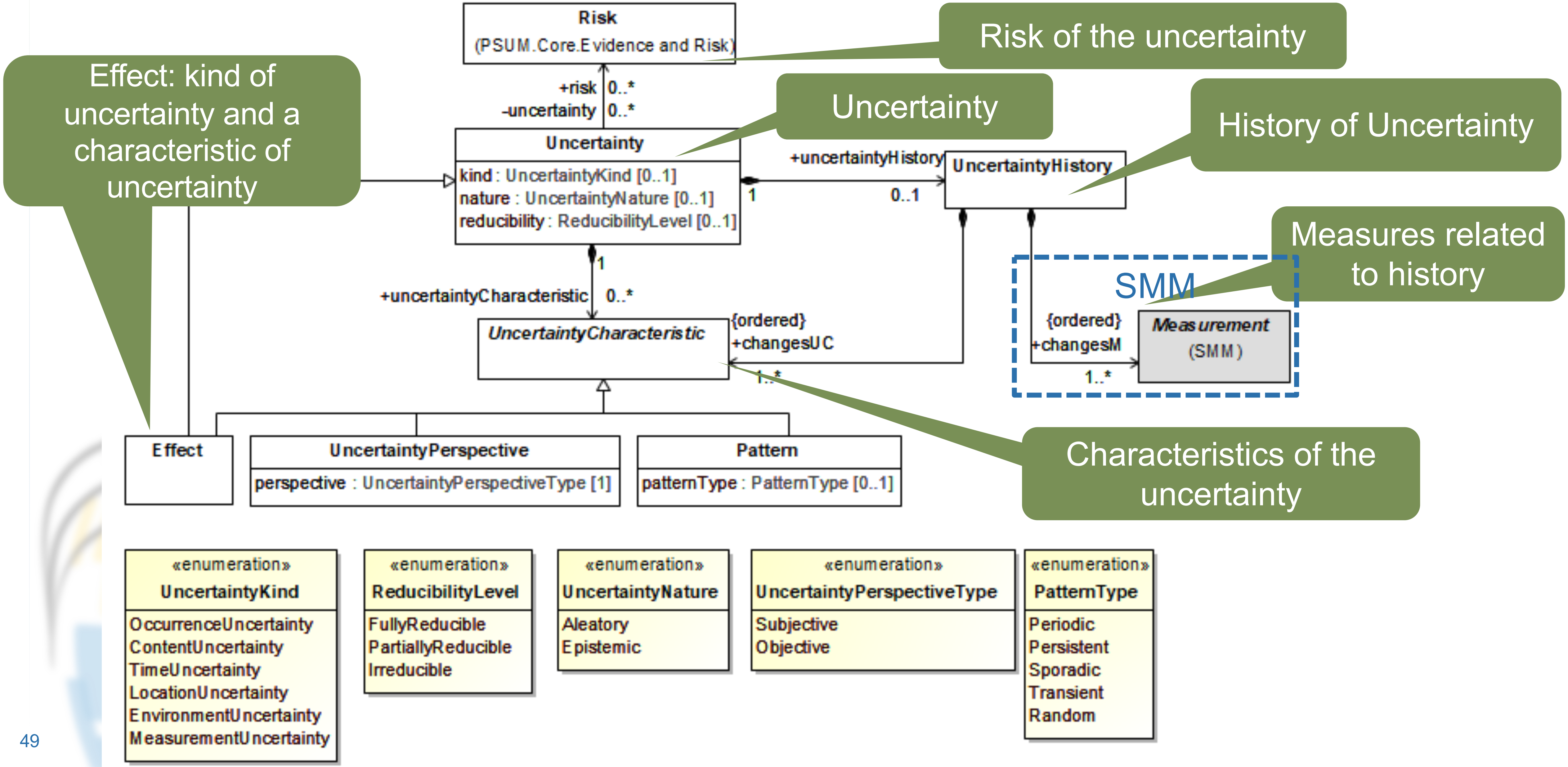
Evidence in PSUM is further described as SACM artefact

"Artifacts correspond to the main evidentiary elements of an assurance case.[SACM 2.3]"

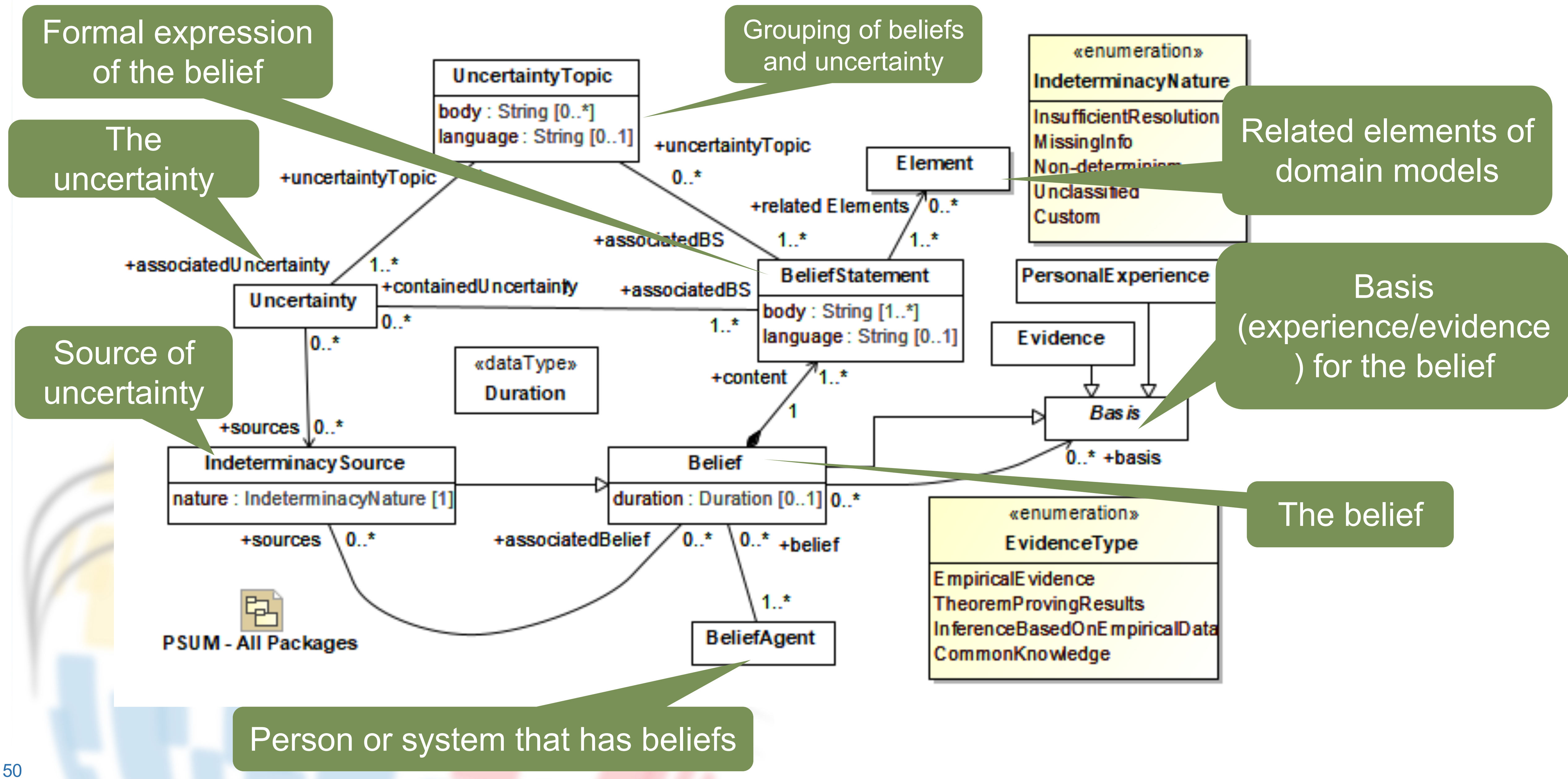
PSUM METAMODEL: CONCEPTS RELATED TO MEASUREMENT



PSUM METAMODEL: CONCEPTS RELATED TO UNCERTAINTY



PSUM METAMODEL: CONCEPTS RELATED TO UNCERTAINTY



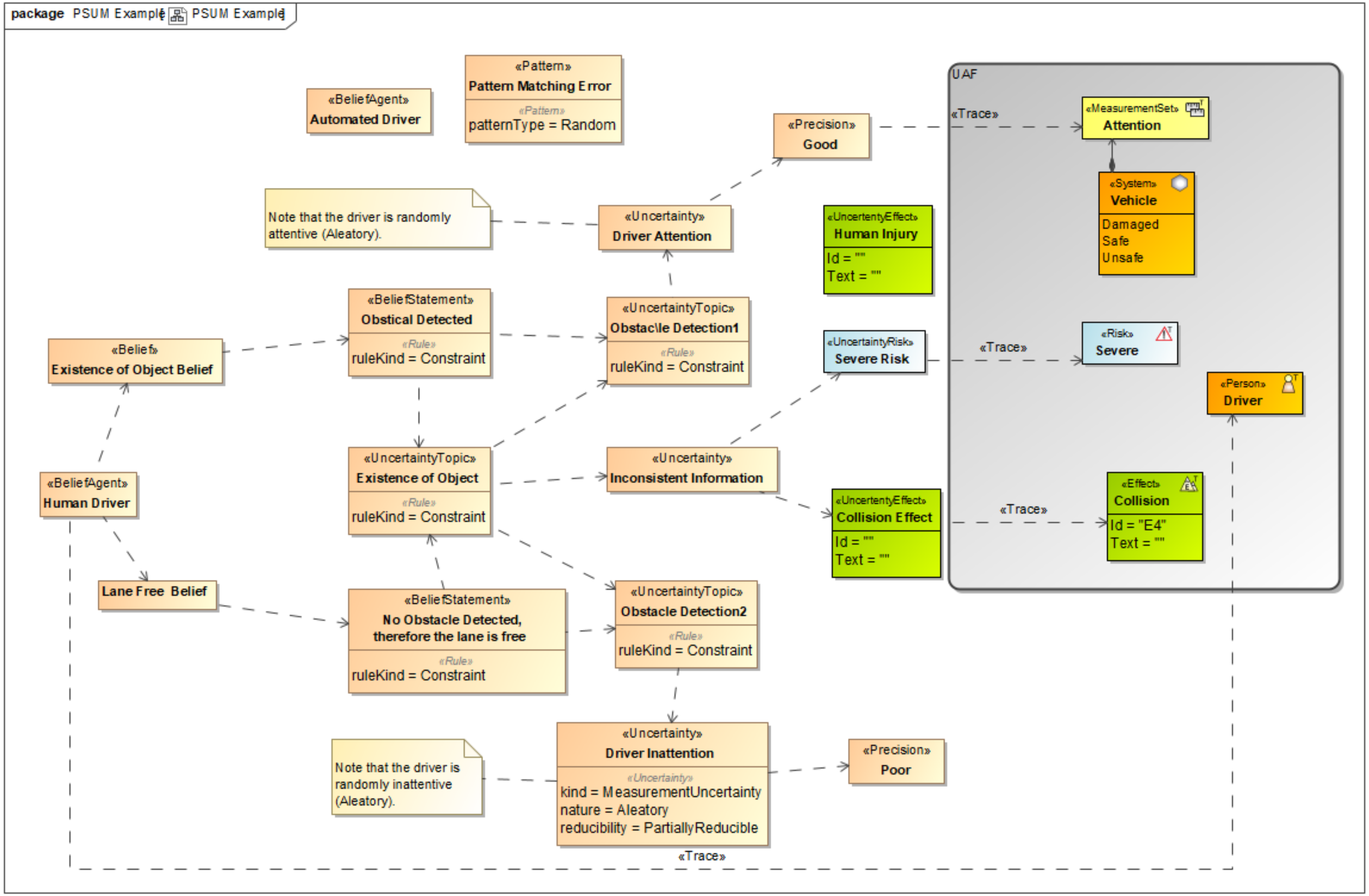
STRUCTURED METRICS METAMODEL

SMM V 1.2 OMG standard that does the following:

- Meta-model for exchanging both measures and measurement information
- Measurements related to structured model assets and their operational environments
- Interchange of measure libraries and structured model related measurements
- SMM is the details of measures and measuring
- In UAF/SysML, there are measures and properties, why SMM?
- SMM is the precise details about the measures described in UAF/SysML and methods of computing comparable values

PSUM FOR UAFML AND SYSML

PROFILE EXAMPLE (SYSML TRACE TO UAF)



INTERESTING LINKS

- **Drivers Don't Understand How Cruise Control Works**
  - https://carbuzz.com/news/drivers-dont-understand-how-cruise-control-works/#:~:text=The%20study%20found%20that%20some,car%20centered%20in%20its%20lane.
- **ADAS Radar Sensor: How it Works & Why it Needs Calibration**
  - **https://caradas.com/adas-radar-sensor/**
- **Target vehicle lane-change intention detection: An approach based on online transfer learning**
  - https://www.sciencedirect.com/science/article/abs/pii/S0140366421000876
- **Radar-based target identification and tracking on a curved road**
  - https://journals.sagepub.com/doi/10.1177/0954407011414462
- **Approaching_the_Reduction_of_Uncertainty_in_Production_System_Design_through_Discrete-Event_Simulation**
  - https://www.researchgate.net/publication/325263850_Approaching_the_Reduction_of_Uncertainty_in_Production_System_Design_through_Discrete-Event_Simulation

TYPES OF RADARS ON VEHICLES

	Range (meters)	General Use	Placement	ADAS Systems
Short Range	0.5–20	For detecting objects in close proximity	Rear vehicle corners	– Blind Spot Detection – Rear Collision Warning – Rear Cross Traffic Alert
Medium Range	1–60	Typically utilized by vehicles as they navigate around town because it’s more effective at detecting objects at medium distances.	Front/Varies	– Front Cross Traffic Assist – Lane Change Assist
Long Range	10–250	Typically used on highways and in specific areas with high traffic density like interchanges and junctions.	Forward facing, near the front bumper or behind the grille	– Automatic Emergency Braking – Adaptive Cruise Control (& Traffic Jam Assist) – Forward Collision Warning

https://caradas.com/adas-radar-sensor/