Realizing Metrics for ODDs and Simulation Scenarios

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Content of this talk

- The Role of ODDs and ODD-related Metrics in AD Development and Safety Validation
- Definition of ODD Metrics and Examples for ODD Metrics
- Useful concepts to calculate ODD metrics: Set operations and IoU
- Some application examples using these concepts

What is an ODD?

Operational Design Domain (ODD) :=

"specific conditions under which a given driving automation system is designed to function"

ISO DIS 21448

"operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics."

SAE J 3016

Possible Representations of ODDs

Drivable area

For drivable area type, we allow [motorways, radial roads, distributor roads].
We do not allow [minor roads].

Drivable area lane specification

For lane specification we allow at least [two] lanes with at least [3.7 m] width.
For lane type we allow [traffic lane].
We do not allow [bus lane, cycle lane, tram lane, emerger
For direction of travel, we allow [left hand traffic].

Environmental

For wind, we allow [up to 15 m/s].
For rainfall, we allow [up to 10 mm/h].
For snowfall, we allow [light snow, moderate snow].
For illumination, we allow [day, night, cloudiness, artificia

Dynamic elements

For agent types, we allow [vulnerable road users, animals,

ASAM OpenODD will be the upcoming formal language to write and exchange ODD specifications!

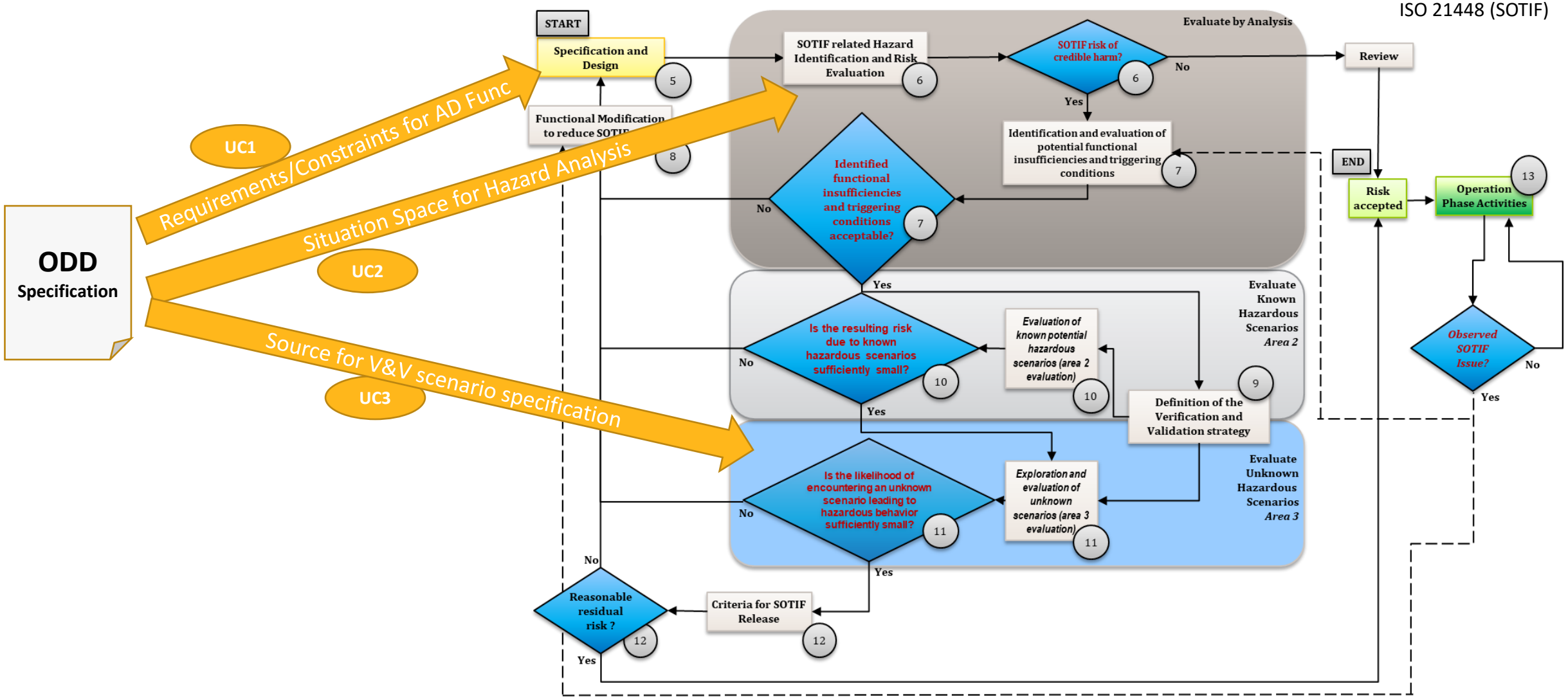
ODD Definition (based on checklist)

type filter text

Feature / Condition	Value
Target Vehicle Types	Passenger cars up to 8 persons, up to 3 tons gross weight
Applicable Road Types for AD Function	Highways in industrialized countries (forbidden for cyclists and horse carriages etc.)
Vehicle speed range during AD operation	0 ... 80 km/h, only forward direction
Allowable number of lanes for ego vehicle' direction	>= 2
Must have road shoulder for emergency stop?	yes
May have pedestrian sidewalk or cycle lane?	no
Allowable time of day / light conditions during AD operation	daytime, night (no streetlamps)
Allowable weather / visibility conditions during AD operation	visibility not less than 500 m, with reduced speed no less than 100 m (no heavy rain, no dense fog, no heavy snowfall)
Allowable road surface conditions during AD operations	paved road, dry or wet, no slippery conditions (like ice, snow covered, leaves, oil)
VRUs around during AD operation	not in the regular case, but in exceptional cases (after accident / car breakdown, in construction site, illegal walkers etc.)
Opposite traffic around during AD operation	no (solid separation required)
Crossing traffic around during AD operation	no
Traffic lights possible during AD operation	not in the regular case, but in exceptional cases (e.g. drawbridge, tunnel, traffic management scheme, construction site)
Required road infrastructure (e.g. guardrails)	yes (unless there is a solid wall or at least 50 m of lateral free drivable space to the respective side of the road)
Restriction on certain traffic situations (e.g. traffic jam)	not in construction sites where traffic priority is signalled by humans
Excluded behavior of other traffic participants (e.g. vehicle in front backing up must end AD operation)	any vehicle around backing up or not aligning with traffic scheme (e.g. standing crosswise after skidding) must end AD operation.
Excluded situations for AD operation (e.g. construction sites)	not in the proximity of tool plazas and border police barriers
Driver must be constantly supervisiong AD operation	no
Driver allowed to perform side tasks during AD operations	yes
Expected emergency take over time by driver	30 s

Usages of the ODD Specification for the AD Safety Process

Process flow acc.
ISO 21448 (SOTIF)



What is an ODD metric (acc. to ASAM OpenODD Concept Document)?

A metric is a function that transforms features or properties of an ODD - alone or in its relation to other ODDs, to scenarios etc. - into a number or an ordered set of qualifiers (e.g. good > medium > bad).

Source: ASAM OpenODD Concept Document (working draft September 2021)

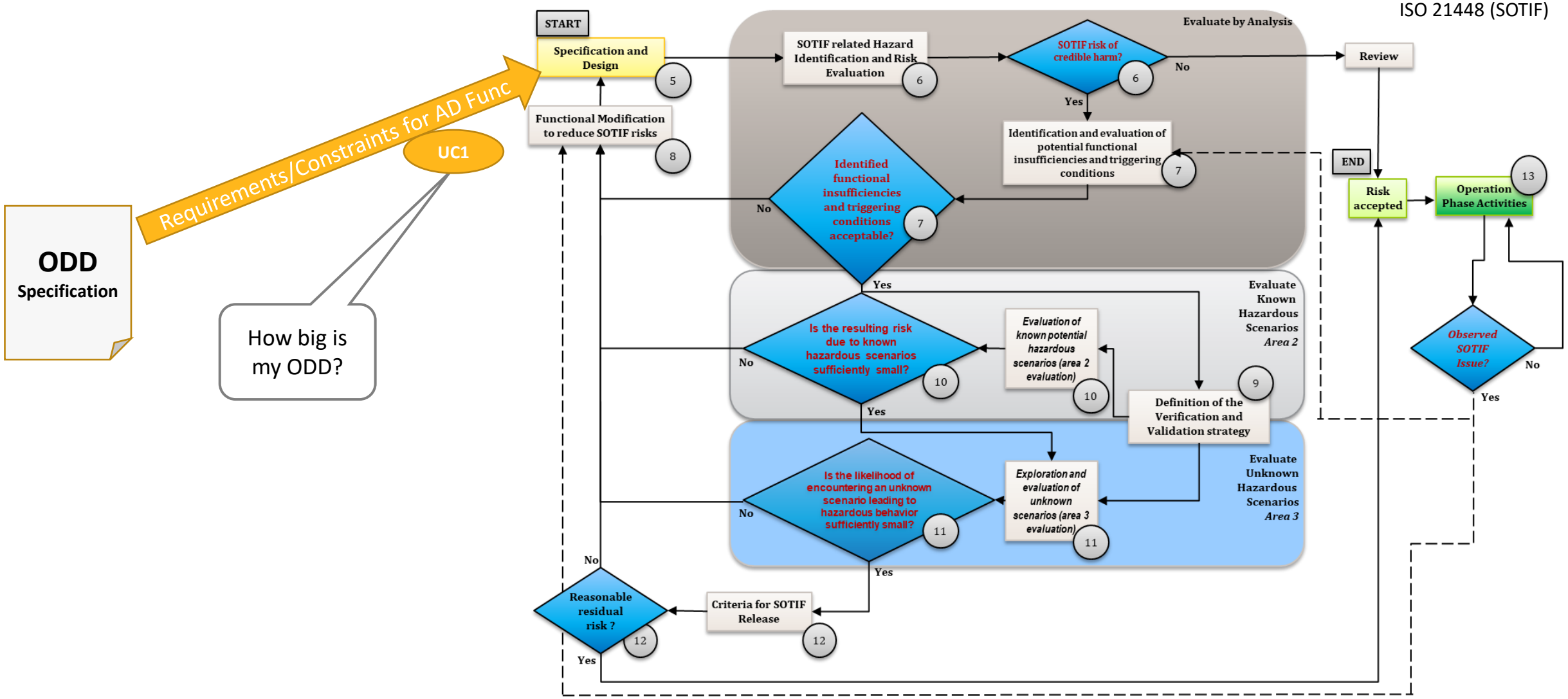
Notes:

- ODD metrics are not just metrics about ODDs, but also metrics relating ODDs and other things (like an ontology, a set of scenarios, the performance of some piece of software to detect whether we are inside the ODD etc.)

- Metrics computation will often need to refer to external data sources (e.g. a database with road or weather statistics)

Examples for metrics about ODDs

Process flow acc.
ISO 21448 (SOTIF)



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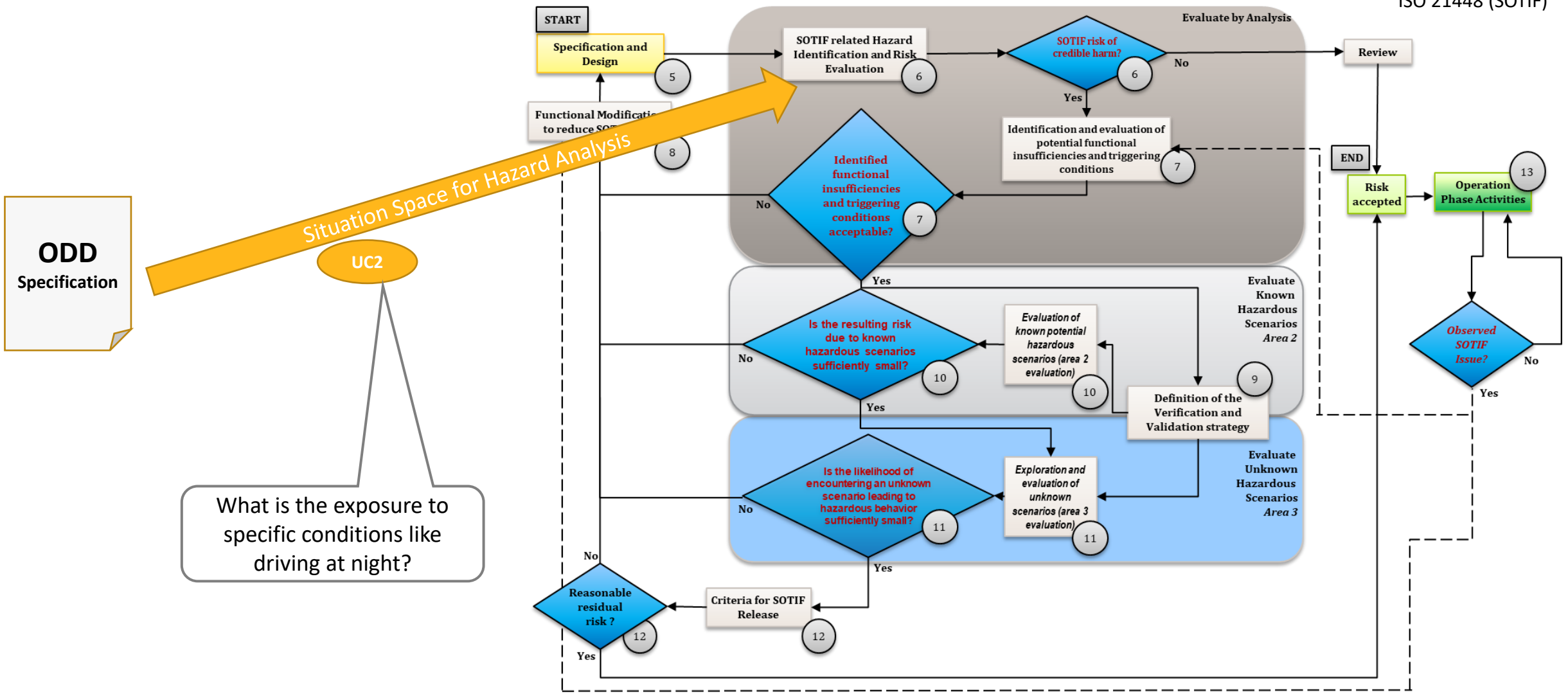

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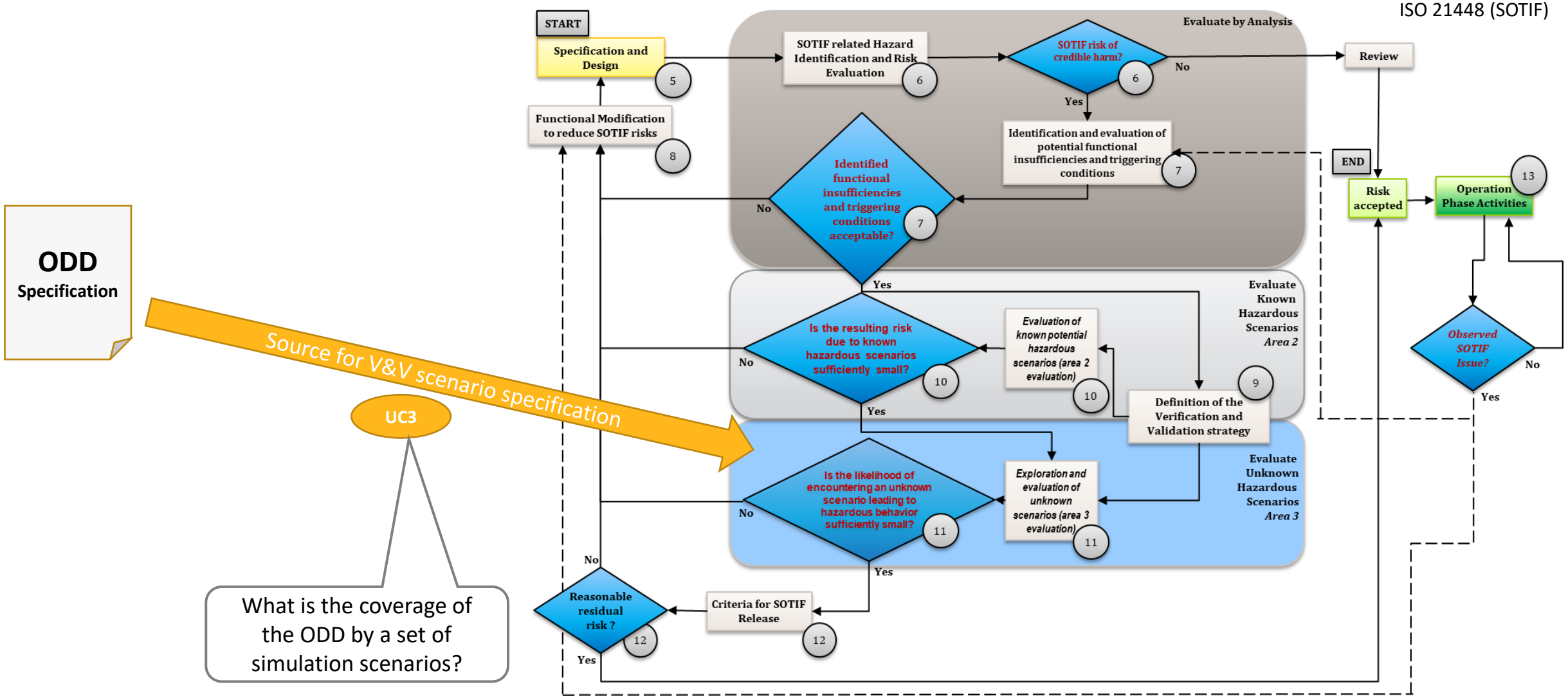


Concepts that could help formalize metrics on ODDs

- Interpret the ontology (on which the ODD is defined) as a multi-dimensional space

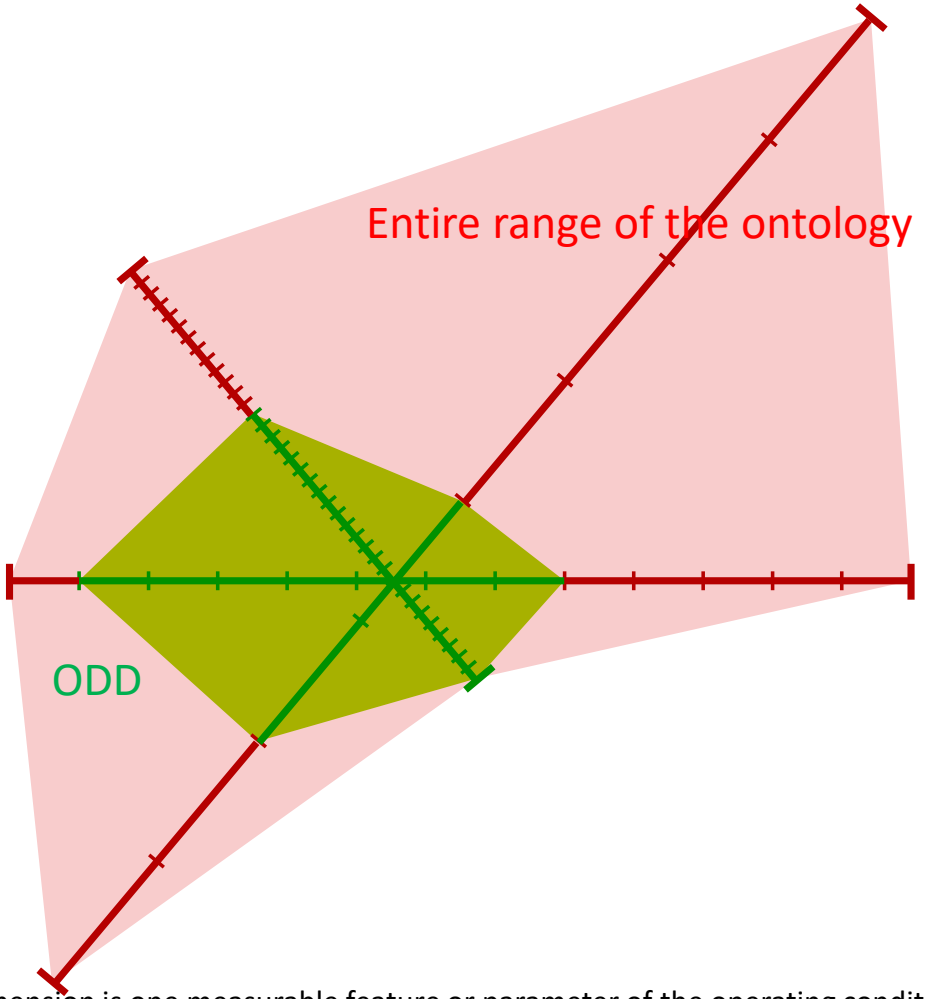
- Each dimension (aspect) is a set, e.g.
  - RoadTypes := {highway, country road, city street, offroad}
  - Weathers := :{clear sky, cloudy, rain, snow, fog}
  - NumbersOfLanes := the set **N** of natural numbers
  - LaneWidths := {2.0 m … 4.0 m}

  → **Ontology** = **Roadtypes** x **Weathers** x **Numbersoflanes** x **Lanewidths**

- The ODD can be regarded as a multi-dimensional sub-set of the whole ontology, e.g.
  - Only highway and country road is allowed, not city or offroad
  - Any weather except fog is allowed
  - Two or more lanes
  - Lane width must be at least 2.5 m

  → **ODD = {highway, country road} x Weathers x {n | n≥2} x [2.5,4.0]**

  → **ODD ⊆ Ontology**



Each dimension is one measurable feature or parameter of the operating conditions
Green area delimits the authorized operating conditions (ODD)
Red parts are operating conditions not intended for AD operation (i.e. outside ODD)

Interpreting an ODD as a multi-dimensional set

- We can now apply set operations (e.g. intersection, union, subset) on ODDs
  (first dimension-wise and in a next step we will do aggregated operations for the whole ODD)

- By this, we can decide wether an ODD1 **is a subset or superset** of ODD2, or what their overlap (**intersection / cut set**) is

- We can also define measures for the „size“ for ODDs or individual ODD dimensions

Deriving Metrics for ODDs using the Set-Approach

- Most trivial metrics are cardinalities (number of elements) for discrete sets
  - Example: Let the ontology contain the following values for road type:
    {offroad, citystreet, countryroad, highway}
  - The ODD of my ADAS function includes countryroad and highway, but not citystreet nor offroad
  - My ODD includes 2 road types (that‘s actually already a metric!)
  - My ODD includes 2 of the 4 known road types, that‘s 50% of all road types (but not 50% of all road kilometers in some country)

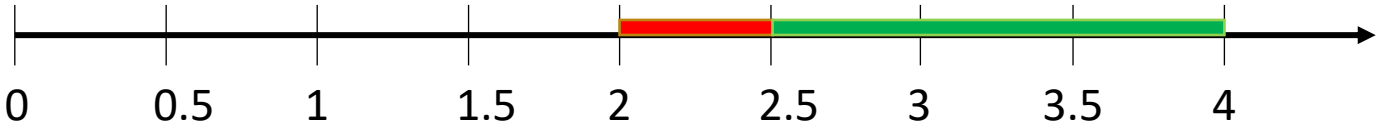
- Now assume we have road type statistics for our target country
  - Highway: 20% of all road kilometers
  - Countryroad: 40% of all road kilometers
  - Citystreet: 30% of all road kilometers
  - Offroad: 10% of all road kilometers

- On what portion of all road kilometers can my car operate with ADAS function switched on?
  - Answer: 60% (It can use highway and countryroad, which together make up for 20% + 40% = 60%)

- Of course there may be other restrictions in the ODD, e.g. by weather, by lane width etc.
- There may be other useful weight factors in addition to occurrence probabilities

Deriving Metrics for ODDs using the Set-Approach

- What if the set for a specific ontology dimension is continuous-valued?
  - E.g. lane width in meters in the range 2.0 to 4.0
  - Then sub-ranges can be formed in a similar way
  - E.g. my ADAS function can handle any road with 2.5 m lane width or more → That‘s 75% of the range



  - And again, this can be weighted with occurrence probabilities (probability densities, actually) or other weighting functions
  - E.g. if only 5% of all roads in a country have lane width below 2.5 m, then I can handle 95%, not just 75%

Deriving Metrics for ODDs using the Set-Approach

- What we did so far were metrics on *individual* dimensions (aspects), like road type or weather
- What if we want one number for the whole ODD with all of its dimensions?
- → We can do a weighted sum over the individual metrics.
- Example:
  - I can handle 75% in terms of lane width. Restrictions by lane width are very serious to me, I'll give them a weight of 0.8.
  - I can handle 50% in terms of road type. Restrictions by road type are not so important to me, I'll give them a weight of 0.2.
- The resulting metrics is the scalar product of the weights vector and the dimension metrics vector

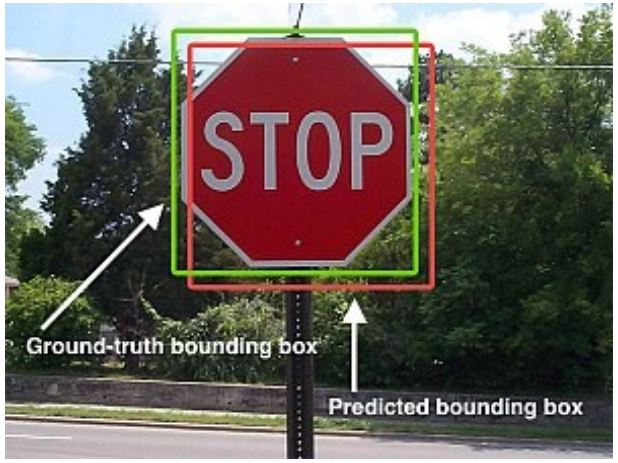
$$M = \begin{pmatrix} w_1 \\ w_2 \\ w_n \end{pmatrix} \cdot \begin{pmatrix} m_1 \\ m_2 \\ m_n \end{pmatrix}$$

  - In the above example M = 0.8 * 0.75 + 0.2 * 0.5 = 0.7

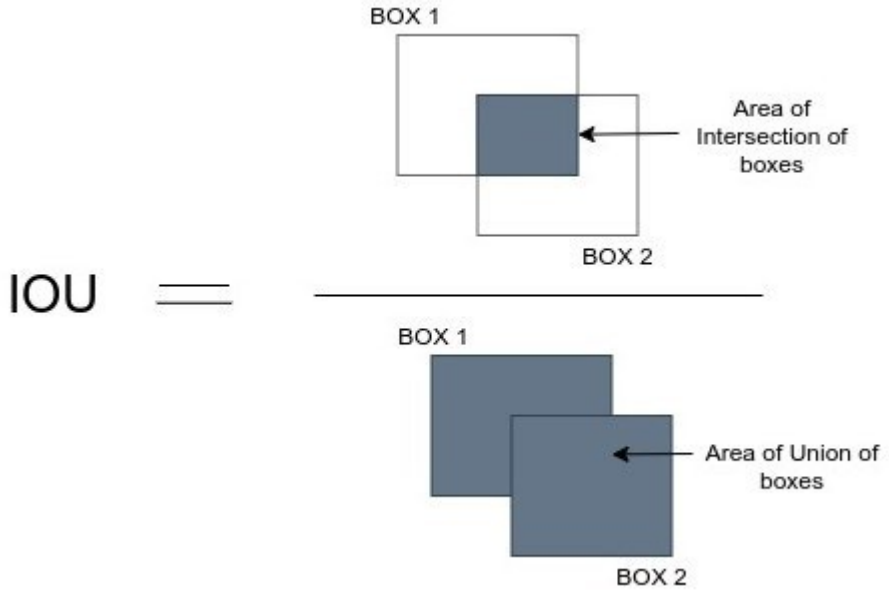
- **Attention**: Things get really tricky when evaluating statistics and the dimensions are not stochastically independent, e.g.
  - Day = 70%, Night = 30%
  - Highway = 40%, Other roads = 60%
  - We could calculate a weighted metric to obtain a percentage of suitable situations
  - But what if that at night almost nobody uses a highway (exposure of night *and* highway is less than the product 0.3 x 0.4)?

A promising concept: Intersection-over-Union (IoU) / Jaccard Index

IoU is an approach to measure similarity (e.g. recognized shapes vs their real counterparts in computer vision)



How well does the predicted bounding box match the real bounding box?



$$J(A, B) = \frac{|A \cap B|}{|A \cup B|}$$

A promising concept: Intersection-over-Union (IoU) / Jaccard Index

The IoU (or Jaccard Index) is a real number in the range 0…1.
The more similar two shapes are in size, proportion and position, the higher the IoU.

0 = Totally Different
1 = Equal

Using IoU as a Similarity Metric for ODDs

- Would you agree that a rectangle of 3x4 cm is more similar to a rectangle of 2.9x4.1 cm than to one of 7x7 cm?
- So wouldn't you also agree that an ODD1 "*Highways, with visibility > 50m*" is more similar to an ODD2 "*Highways, with visibility > 55m*" than to an ODD3 "*City street at low speed under any visibility conditions*"?

- **So why not transfer the idea of IoU to compare different ODDs?**

- Issue: An ODD is not a rectangle => How to adapt the idea of IoU to ODDs?
- Our approach to interpret an ODD as a multi-dimensional set vector can help us out of this!
- As soon as we are able to say
  - What a cut set is
  - What a union set is
  - What a measure for the size of a set is

  …we can compare two ODDs A and B to each other using IoU!

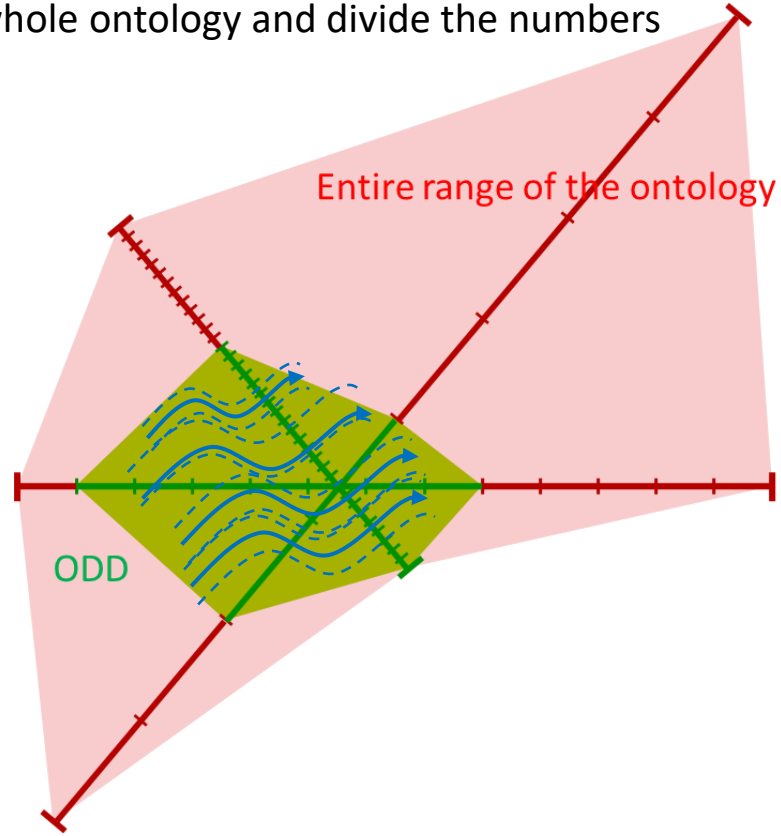
$$J(A,B) = \frac{|A \cap B|}{|A \cup B|}$$

- The formulas are first applied dimension-wise and can then be weighted

Some ODD Metrics Examples Using IoU

1. „How big“ is my ODD? → IoU between ODD and whole ontology (dimension-wise, then form weighted sum)
2. „How similar are ODD1 and ODD2“ → IoU between the two ODDs
3. „How much bigger is ODD1 than ODD2?“ → Calculate for each ODD the IoU with the whole ontology and divide the numbers
4. „How well is my ODD covered by a given set of test scenarios?“
   → Form IoU of chosen scenario set and ODD

Caution: This requires additional considerations because scenarios are „infinitely thin lines“ that do not cover an area
→ one approach is to build on *logical* scenarios instead of *concrete* scenarios.

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