Redundancy schemes with low-level sensor fusion for autonomous vehicles

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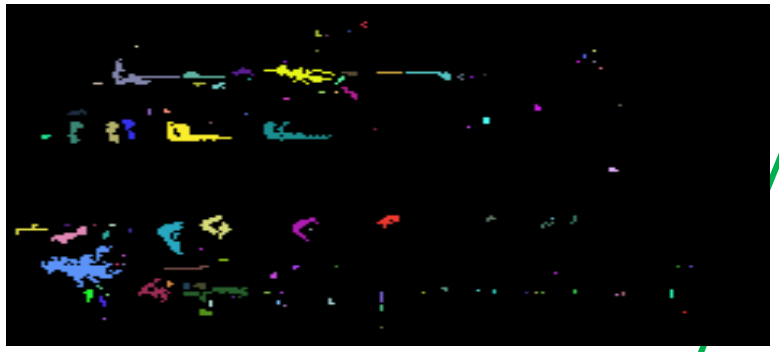
The Driving perception challenge

- Sensing



- Detecting

- Measurement
- Classification

- Tracking and environmental model

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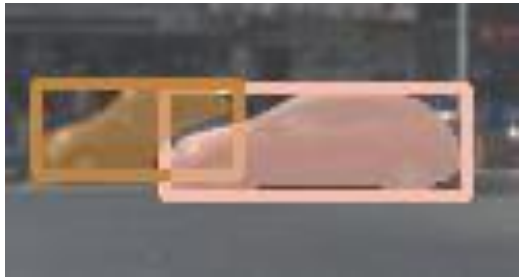
Detection approaches

- Image based DNN ***BBox*** detection
  - Supervised

- Image based DNN ***Pixel Semantic Instance*** segmentation
  - Supervised



- Point-cloud based ***Object Cloud*** detection
  - Un-Supervised

- RGB-D Rich model based ***shape & look*** *detection*
  - Un-Supervised

The automotive detection problem

- "*Don't miss anything that can harm you or be harmed by you*"

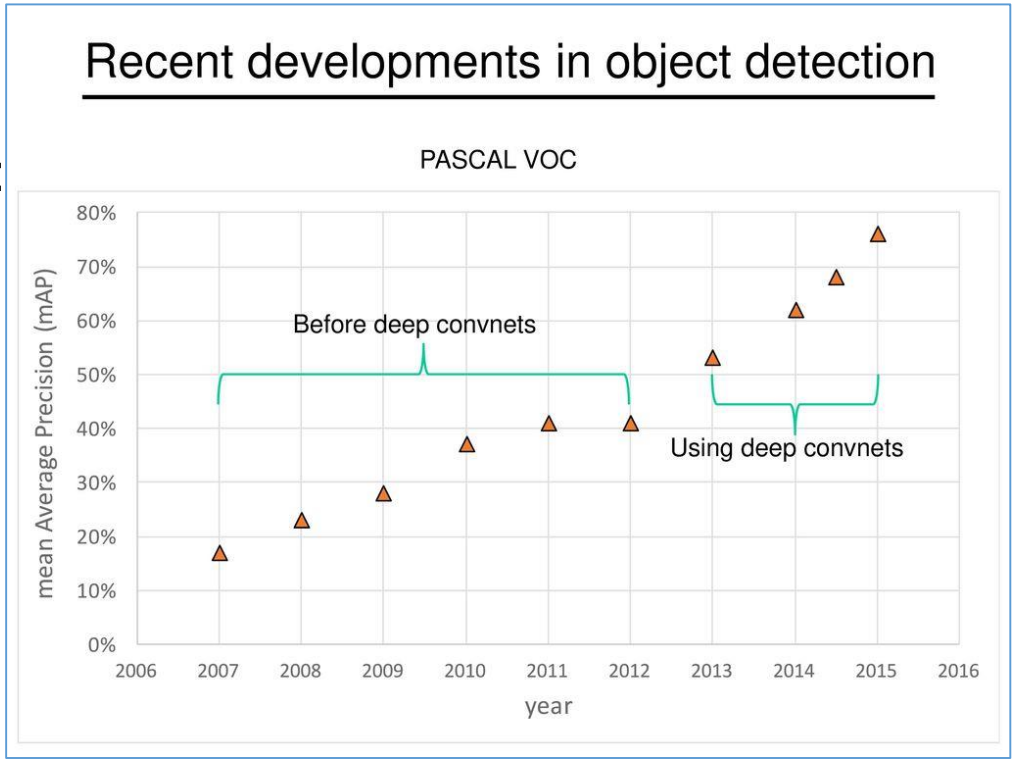
  = Need to detect anything that blocks one's way

- How much is "anything" – it's a statistical question
  ➔ There's always some chance to miss…

- In terms of true positives the gap narrowing:

  70→80→90→95→99…

  BUT



https://slideplayer.com/slide/12533747/

The automotive detection problem

- "*Don't miss anything that can harm you or be harmed by you*"

  = Need to detect anything that blocks one's way

- How much is "anything" – it's a statistical question
  ➔ There's always some chance to miss…

- In terms of true positives the **linear gap** is small: **90→99→99.9→99.99…**

- But in terms of false rate, the **logarithmic gap** is **orders of magnitude** away: **10^{-1}→10^{-2}→ 10^{-3}→10^{-4}→… 10^{-9}**

- To minimize probability of loss we can
  1. Improve detectors (Better HW, Better algorithms)
  2. Add uncorrelated **sensors ➔ Sensor fusion ,** $P_{loss12}=P_{loss1}*P_{loss2}$
  3. Add uncorrelated **detection algorithms ➔ Detections fusion**
  4. Add **sensor redundancy ➔ Failure prevention ,** $P_{loss} \sim \{P_{loss1}*P_{loss2}, P_{loss1}, P_{loss2}\}$

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Sensor characteristics

	Density Points/Scan	Color	Position	Velocity	Size	Class	Low Visibility
Radar	10^3		✓	✓		~~	✓
Lidar	10^5		✓		✓	~~	✓
Thermal Camera	10^5					✓	✓
Vision Camera	10^7	✓	~~		~~	✓	

➢ **Camera provides orders on magnitude more data**

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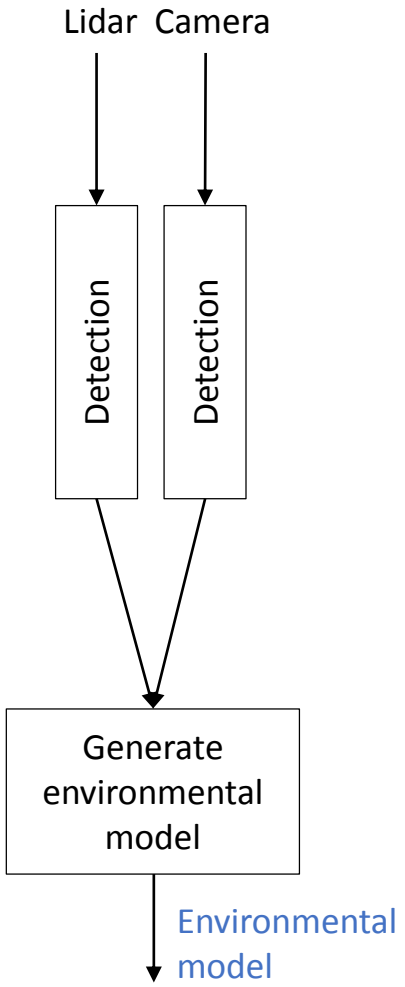
Sensor fusion schemes

Object level fusion



- Object fusion advantages
  - Simpler algorithms
  - Simpler and modular system architecture
  - Independent failure tolerance ?

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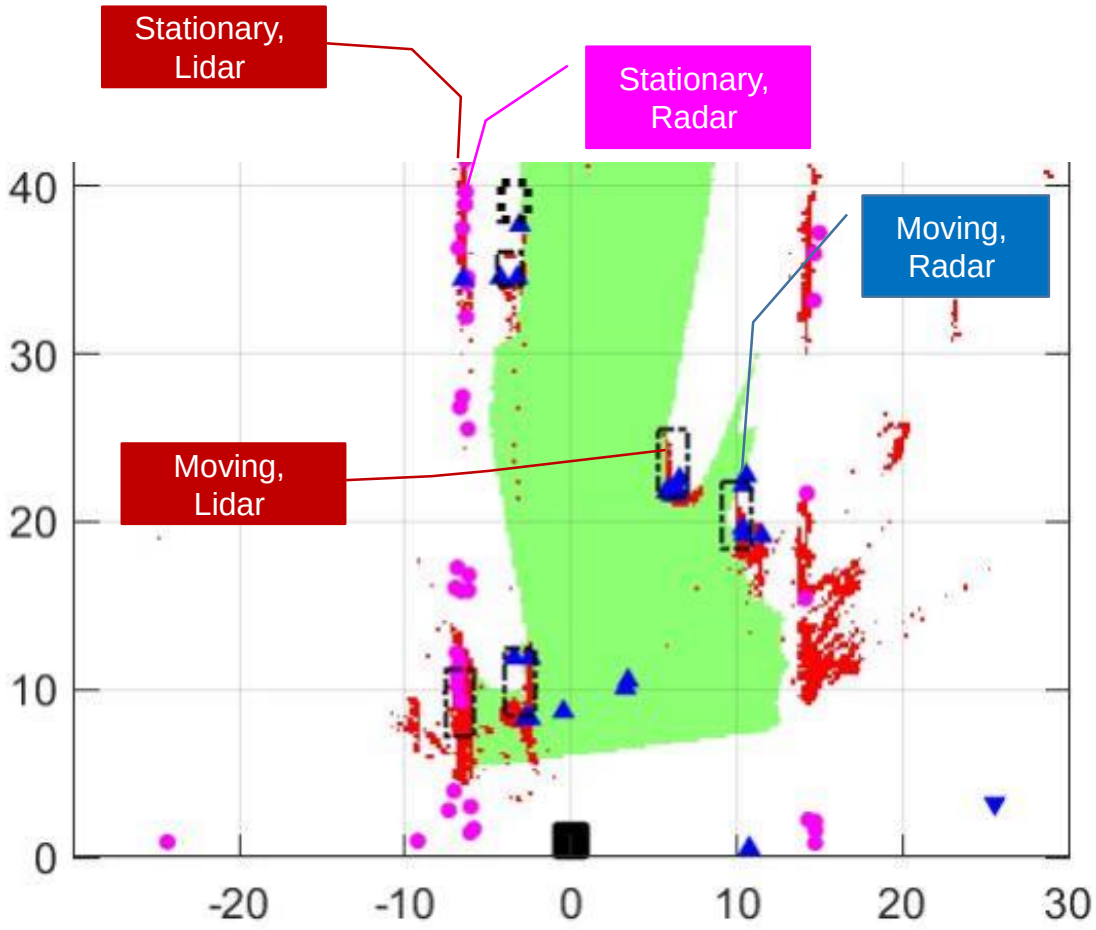
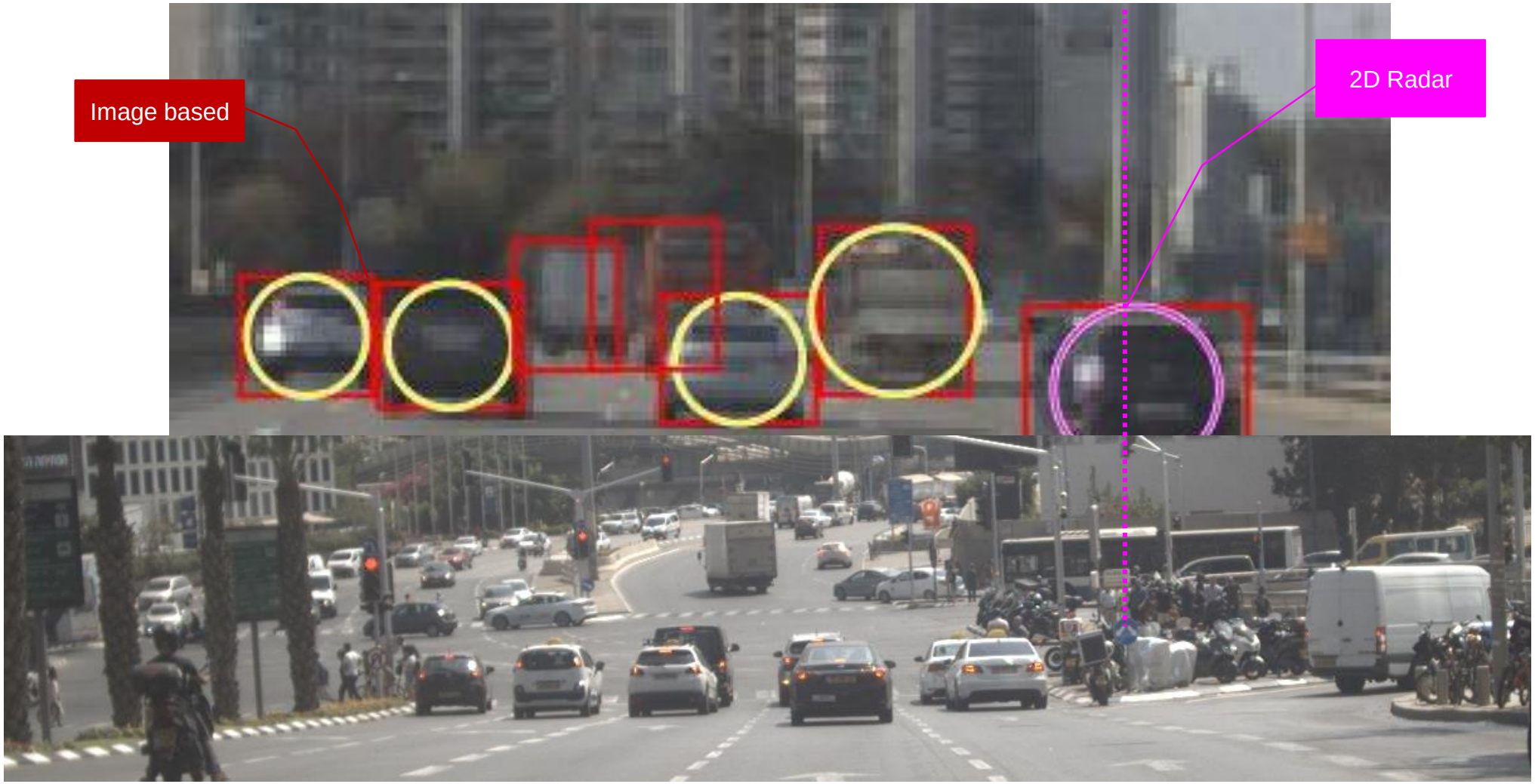
Object level fusion, Radar and Lidar

Bird's eye view



➢ **Works well with distance sensors**

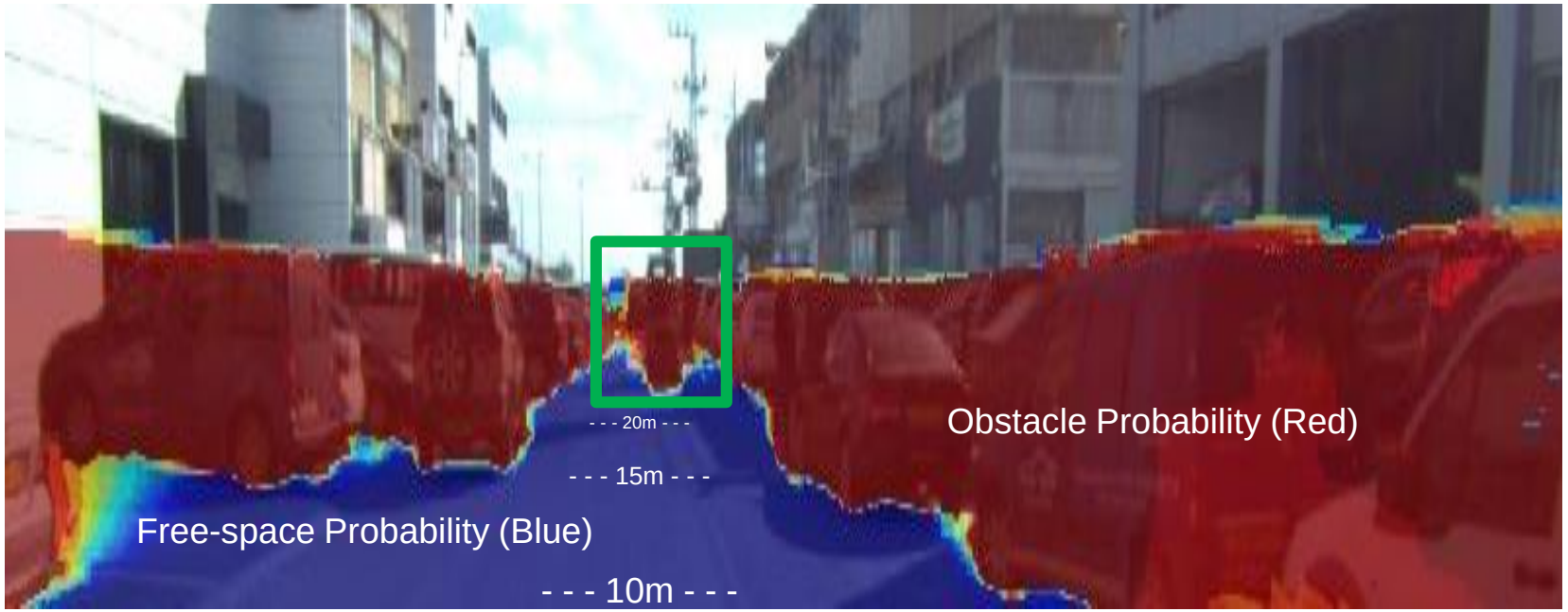
Object level fusion, Image & 2D-Radar



➢ **Object fusion: difficult on complex situations**

Distance from Camera: Based on heuristics

Front-view



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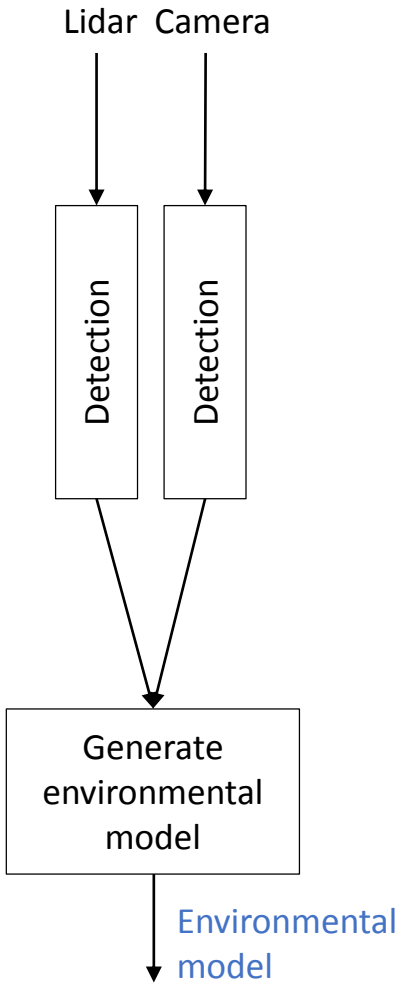
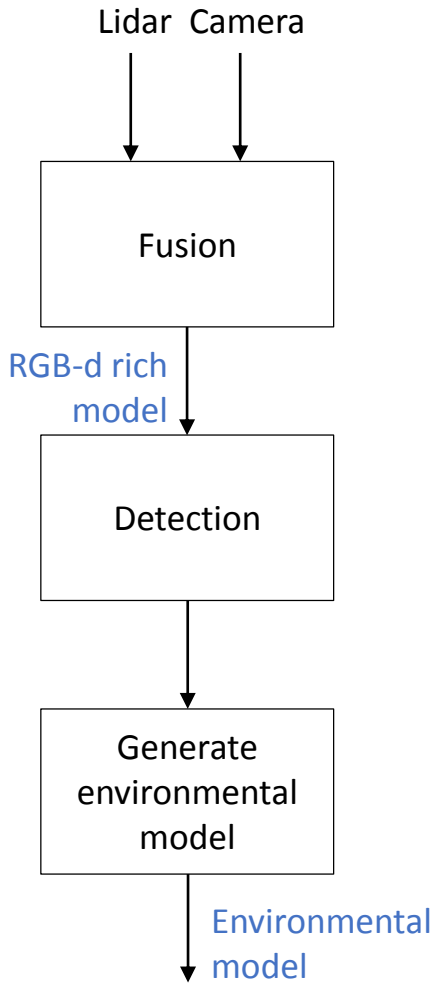
Sensor fusion schemes

Object level fusion



Low-level fusion



- Low-level fusion advantages
  - Expanded content of information
  - Super resolution for sparse sensors
  - Joint probabilities at the pixel level
  - Best overall detection performance
  - Prone to sensor failure ?

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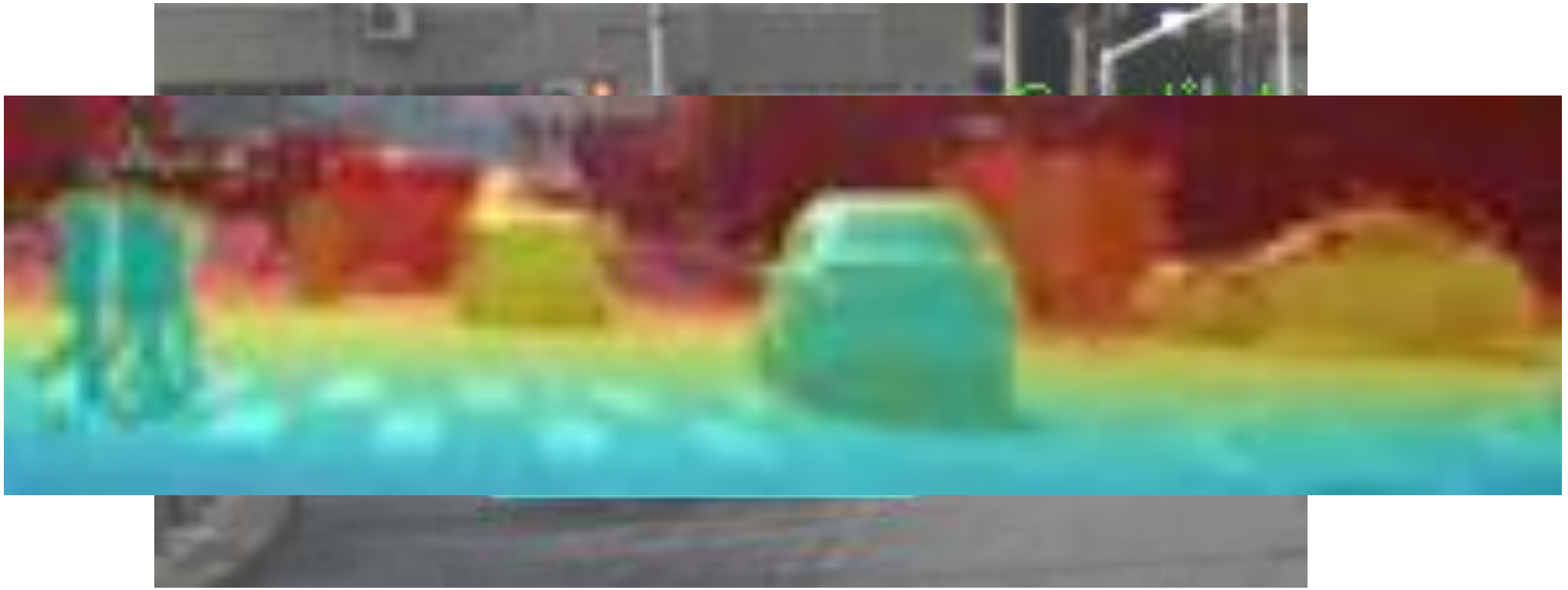
Low-level fusion – attaching accurate depth to every pixel



- Lidar points are up-sampled to fill-up gaps

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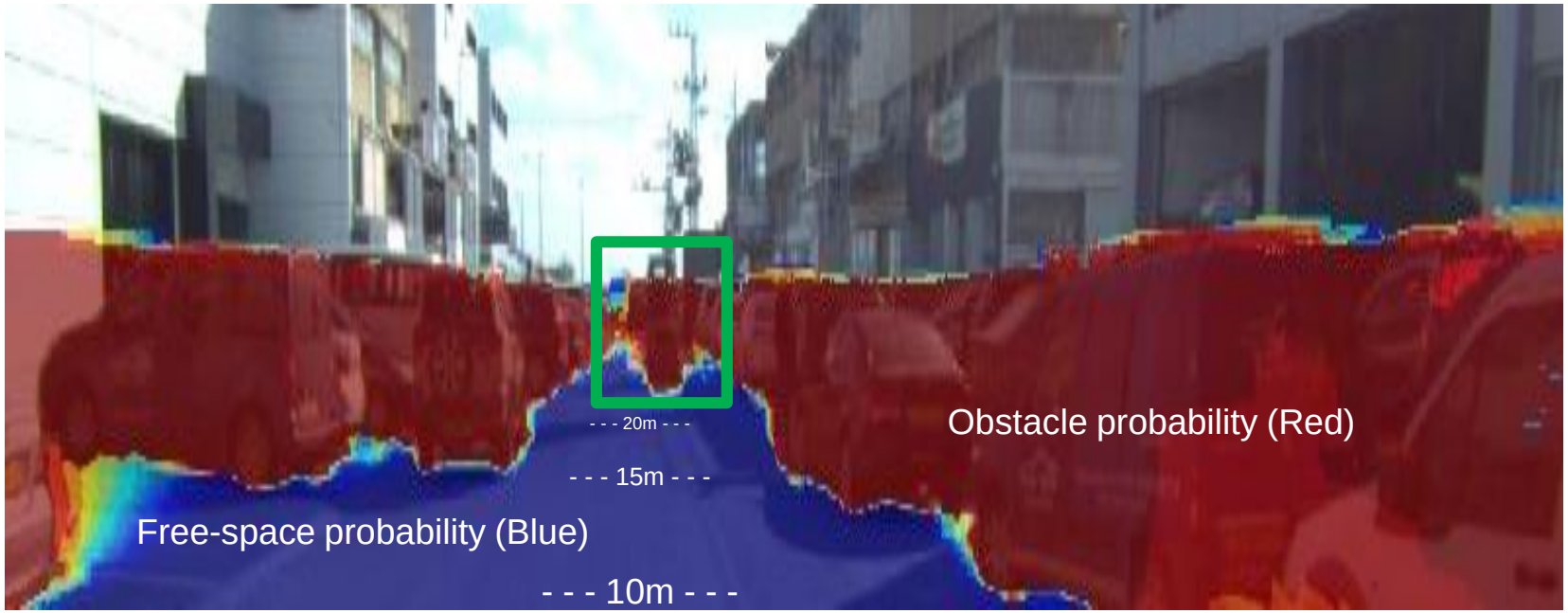
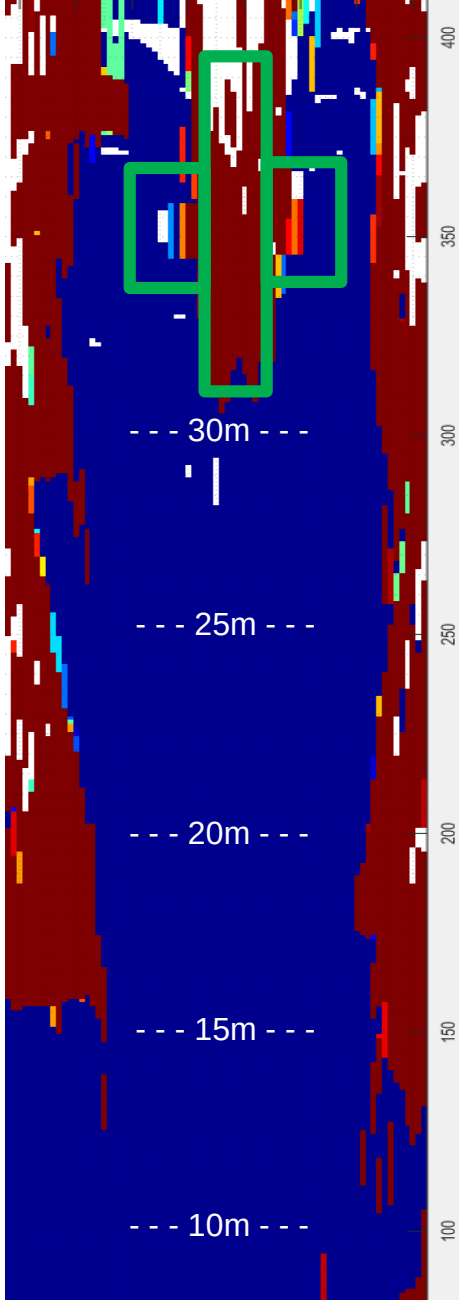
Distance from Camera: Based on heuristics

Top view Transform

Bird's eye view

Front-view





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Thermal Camera	10^5					✓	✓
CMOS Camera	10^7	✓	~~		~~	✓	
Fusion RGB-d	10^7	✓	✓	✓	✓	✓	✓

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Redundancy Strategies

- Sensor overlap
  - Two identical **Cameras**, (nearly) same field of view
  - Short range (wide) and long range (tele) **Cameras**
  - Medium range and long range **Radar**

- Alternative technology
  - **Lidar** vs (3D) **Radar**
  - **RGB-VIS** camera vs **Thermal-IR** camera

Front-facing sensors

Lidar

Wide camera

Tele camera

Radar

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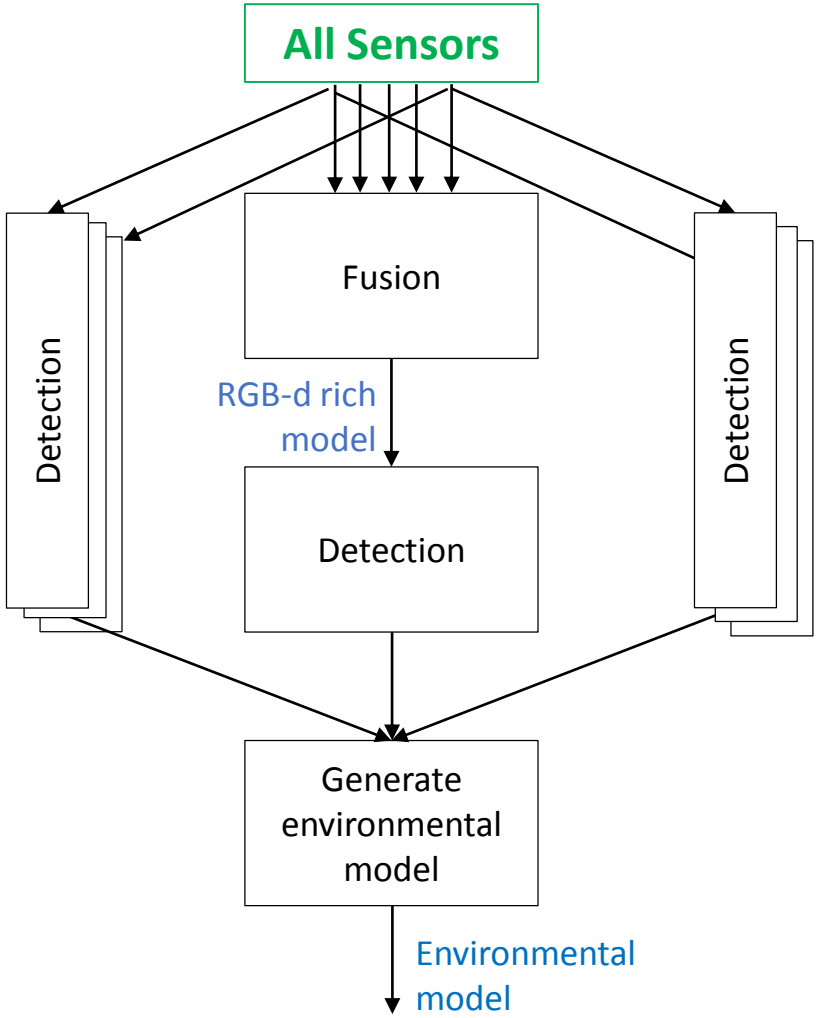
Sensor Redundancy, Maximizing:
> Detection Performance
> Failure tolerance

Multi-level fusion



Overlap sensors
- Max Redundancy

Overlap Technology
- Max Performance
- Visibility tolerance

Low-level Fusion
- Best Performing Algorithm

Alternative detection paths
- Max Robustness
- Failure Tolerance

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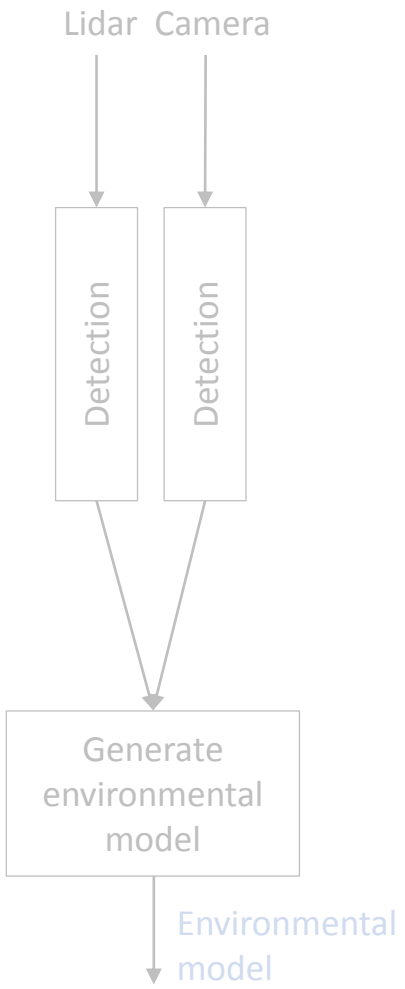
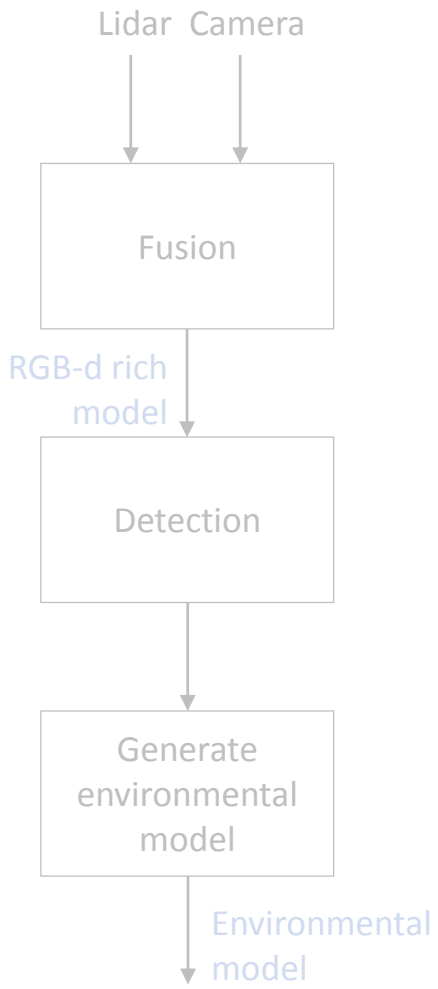
Alternative fusion schemes

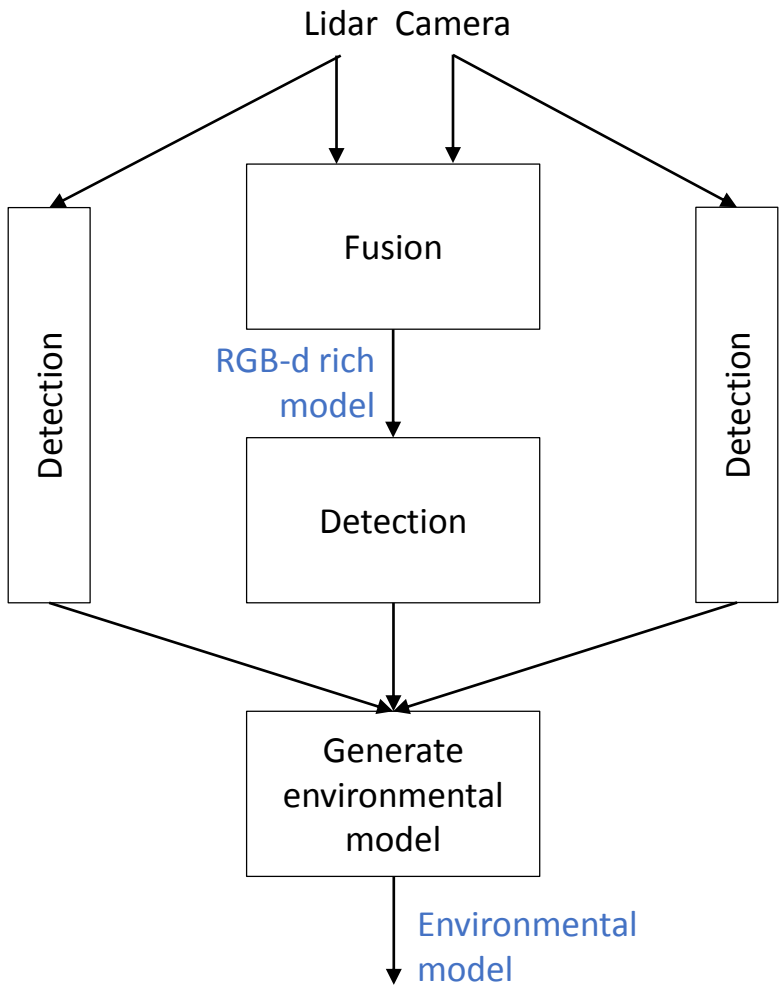
Object level fusion



Low-level fusion



Multi-level fusion



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Failure & Recovery Modes in Multi-level sensor fusion

Calibration failure	Sensor fusion deteriorates	Use direct detection Do auto calibration
Sensor blocked	Sensor fusion deteriorates	Recovered through sensor overlap
Sensor failure	Sensor fusion deteriorates	Recovered through sensor overlap
Visibility conditions	Sensor fusion Performance deteriorates	Recovered through alternative sensor technplogy

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Sensor failure impact

- Does faulty sensor reduce perception quality?
  Yes, but only a little if **properly designed**
- Will it cause ‘black spots’?
  No, if sufficient **redundancy** exists
- Will the car be *able* to keep driving?
  Yes, but maybe **slower**
- Will the car be *allowed* to keep driving?
  Yes, but *only to the nearest workshop*

➢ **Upon failure, AV is not expected to behave as usual**

Summary

- To **maximize failure tolerance**
  - Select best detectors: **best HW, best algorithms**
  - Use uncorrelated **sensors ➔ Sensor fusion ,** $P_{loss12}=P_{loss1}*P_{loss2}$
  - Use uncorrelated **detection algorithms ➔ Detections fusion**
  - Add **sensor redundancy**

- Environmental perception benefits from **redundancy through overlap**
  - ✓ Multiple sensors of same type (e.g., low cost image sensors)
  - ✓ Alternative technologies (e.g., higher-cost Lidar and Radar)

- **Multi-level sensor fusion** supports redundancy through flexibility
  - ✓ **Low-level Raw-Data sensor fusion** provides best detection
  - ✓ **Alternative detection modalities** provide inherent fault tolerance

- Proper **Automotive response** required for minimizing probability of loss
  - It is OK to expect reduced speed


Thank you