# CAREER: Certifiable Perception for Autonomous Cyber-Physical Systems

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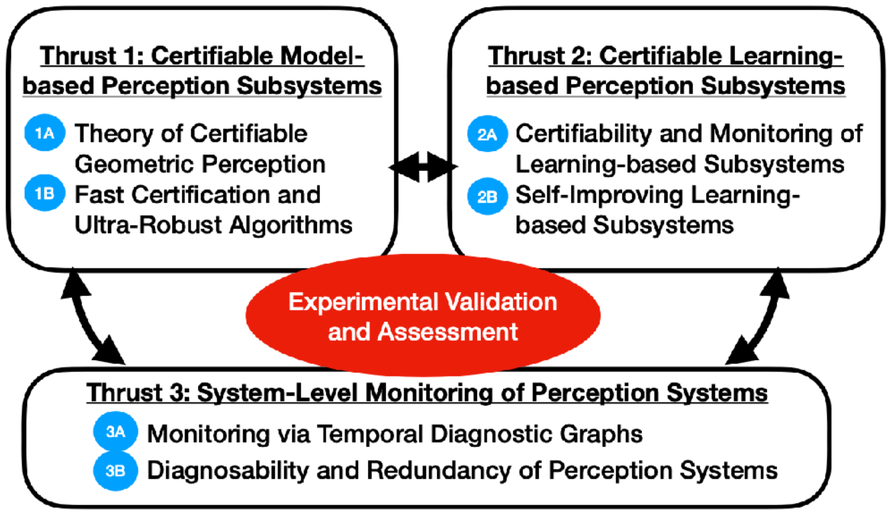
## Challenge:

- Perception is a **key capability** of autonomous CPS, from self-driving cars to autonomous drones & service robots
- **Perception failures** can cascade to catastrophic system failures and compromise human safety
- **Technical challenges**:
  - model-based perception subsystems involve hard optimization/estimation problems
  - learning-based perception subsystems perform poorly outside the training domain and are not interpretable
  - lack of rigorous system-level perception monitoring

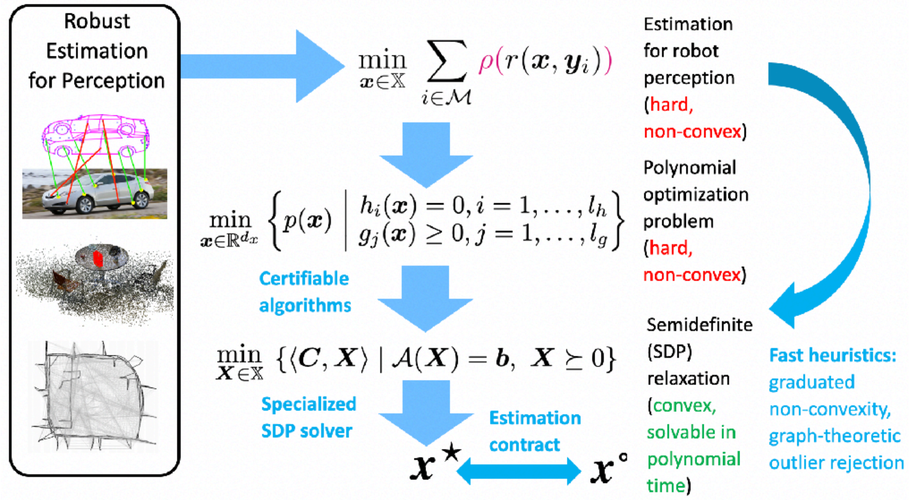
## Proposed Solution:

- **Foundations of certifiable perception**: toolkit of theory, algorithms, implementations to monitor and drastically reduce subsystem and system-level failures of perception




## Highlight 1: Certifiable Model-based Perception [1]

- First polynomial-time certifiably optimal algorithms for outlier-robust estimation arising in perception




## Highlight 2: Certifiable Learning-based Perception [2]

- Certification & self-supervision are twin challenges: detecting correct results enables self-supervised learning

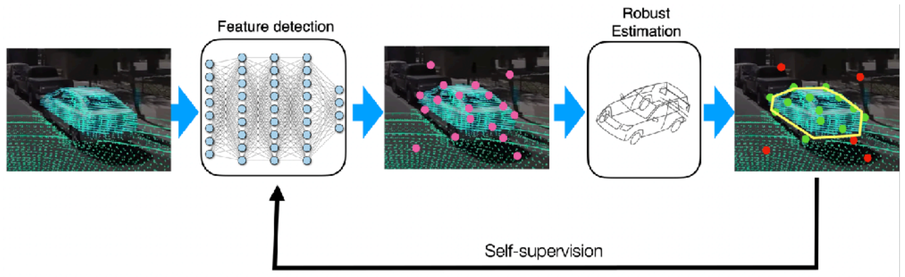
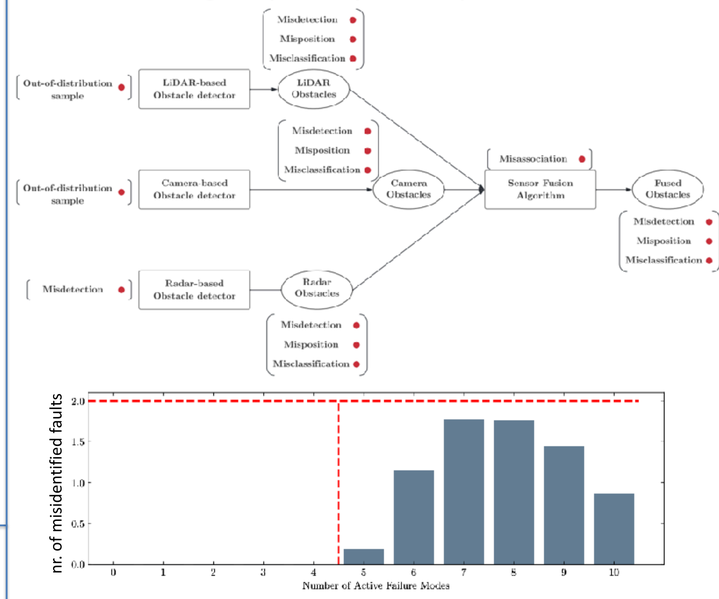



TABLE I: Evaluation of Ensemble and baselines on the YCBV dataset.

| ADD-S | ADD-S (AUC) | Coffee Can | | Sugar Box | | Tuna Can | | Wood Block | | Scissors | | Large Clamp | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RKN (Real) | | 0.90 | 0.65 | 0.14 | 0.16 | 0.62 | 0.50 | 0.05 | 0.18 | 0.01 | 0.16 | 0.12 | 0.23 |
| CosyPose (Real) | | 0.83 | 0.63 | 1.00 | 0.81 | 0.93 | 0.70 | 0.27 | 0.29 | 0.22 | 0.28 | 0.86 | 0.67 |
| Self6D++ (SSL) | | 0.25 | 0.29 | 0.36 | 0.43 | 0.32 | 0.33 | 0.26 | 0.25 | 0.11 | 0.14 | 0.38 | 0.32 |
| Ensemble (SSL) | | 1.00 | 0.77 | 0.99 | 0.79 | 1.00 | 0.76 | 0.98 | 0.69 | 0.96 | 0.73 | 0.97 | 0.78 |
| Ensemble (SSL, $oc = 1$) | | 1.00 | 0.78 | 1.00 | 0.83 | 1.00 | 0.79 | 1.00 | 0.74 | 1.00 | 0.77 | 0.97 | 0.78 |

## Highlight 3: System-level Monitoring [3]

- Diagnostic graphs: framework for runtime monitoring of perception systems




- Deterministic bounds on diagnosability, PAC bounds on nr. of misidentified faults
- Monitoring runs in real-time

## Impact:

- 7 journal papers, 4 conference paper
- 2 best papers and 2 best paper finalists
- algorithms included in Matlab & GTSAM; open-source implementations adopted by JPL, NASA, Air Force SBIR, and others
- work on system-level monitoring expanded with NVIDIA
- Heng Yang now faculty at Harvard
- 25 seminars (including 1 TEDx talk) in 2023 (61 since start of the project)

[1] H. Yang and L. Carlone. Certifiably optimal outlier-robust geometric perception: Semidefinite relaxations and scalable global optimization. IEEE Trans. Pattern Anal. Machine Intell. (PAMI), 2022.
[2] R. Talak, L. Peng, and L. Carlone. Certifiable 3D object pose estimation: Foundations, learning models, and self-training. IEEE Trans. Robotics (TRO), 39(4):2805–2824, 2023.
[3] P. Antonante, H. Nilsen, and L. Carlone. Monitoring of perception systems: Deterministic, probabilistic, and learning-based fault detection and identification. Artificial Intelligence Journal (AIJ), 2023.

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