

# Robotic Mapping and Monitoring of Data Centers

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# Data Center Motivation

- Data centers (DCs) worldwide emit the equivalent of 50% of all airplane carbon dioxide emissions
- Roughly equivalent to the total output of Malaysia, little more than the Netherlands
- HVAC systems utilize 30-50% of the total data center energy consumption

# Monitoring

- Static sensors provide spatially sparse, temporally dense thermal measurement
- Retrofitting older data centers can be cost prohibitive
- Existing sensors can be manually integrated into current asset management and analytics packages



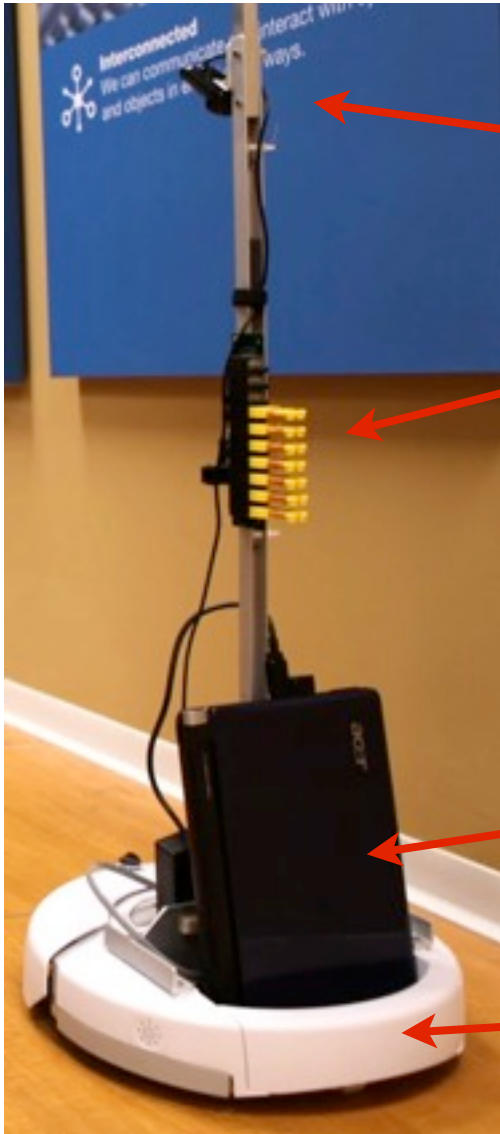
# First Attempt



# Proof-of-Concept

- Autonomous robotic platform
  - Low cost
  - Robust
  - Layout Generation

# Proof-of-Concept



Camera

Thermocouple Interface

2m Sensor Pole

1.6GHz Atom

iRobot Create



**Video**

Can we selectively sample a subset of data center locations, while accurately capturing the overall thermal profile?

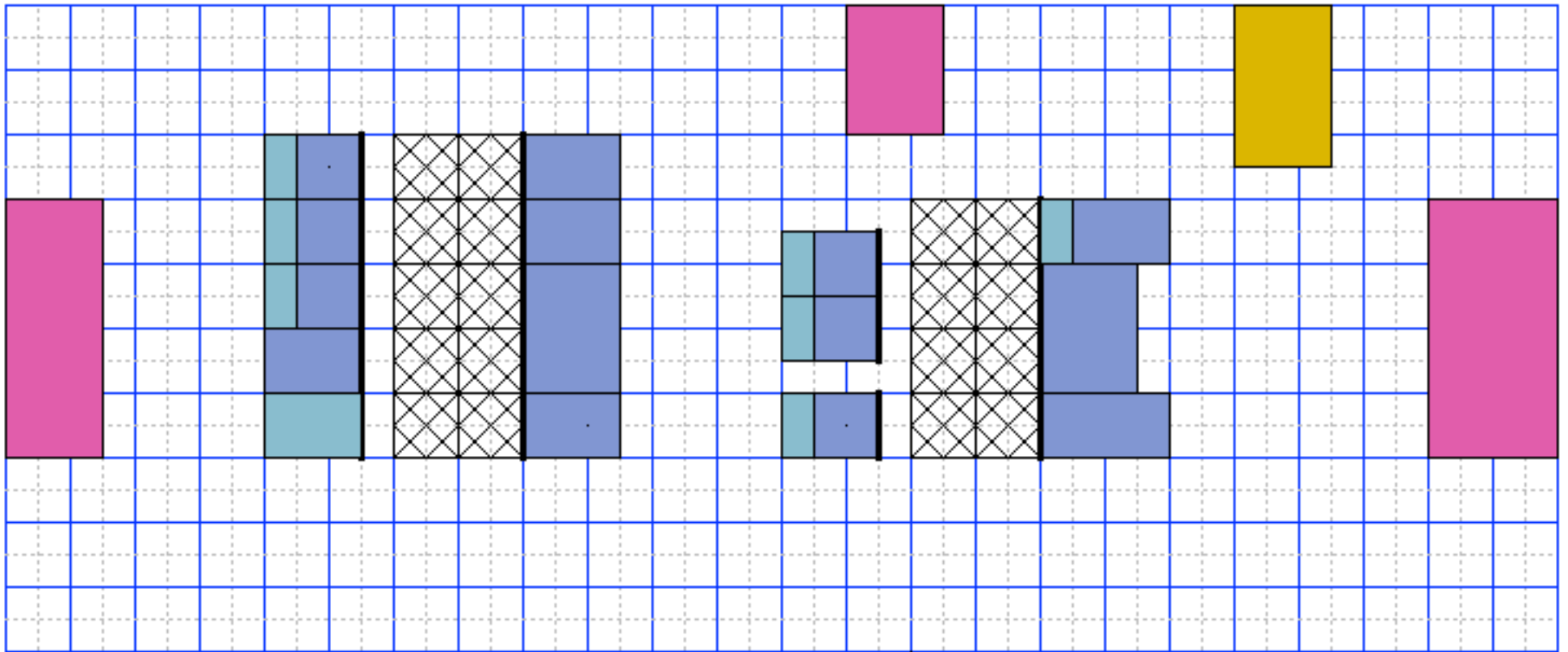
Yes! Our solution uses Gaussian Process Regression [Singh et al., Guestrin et al.] to

1. Interpolate acquired samples
2. Estimate interpolation uncertainty
3. Select sub-sampling locations using mutual information or entropy

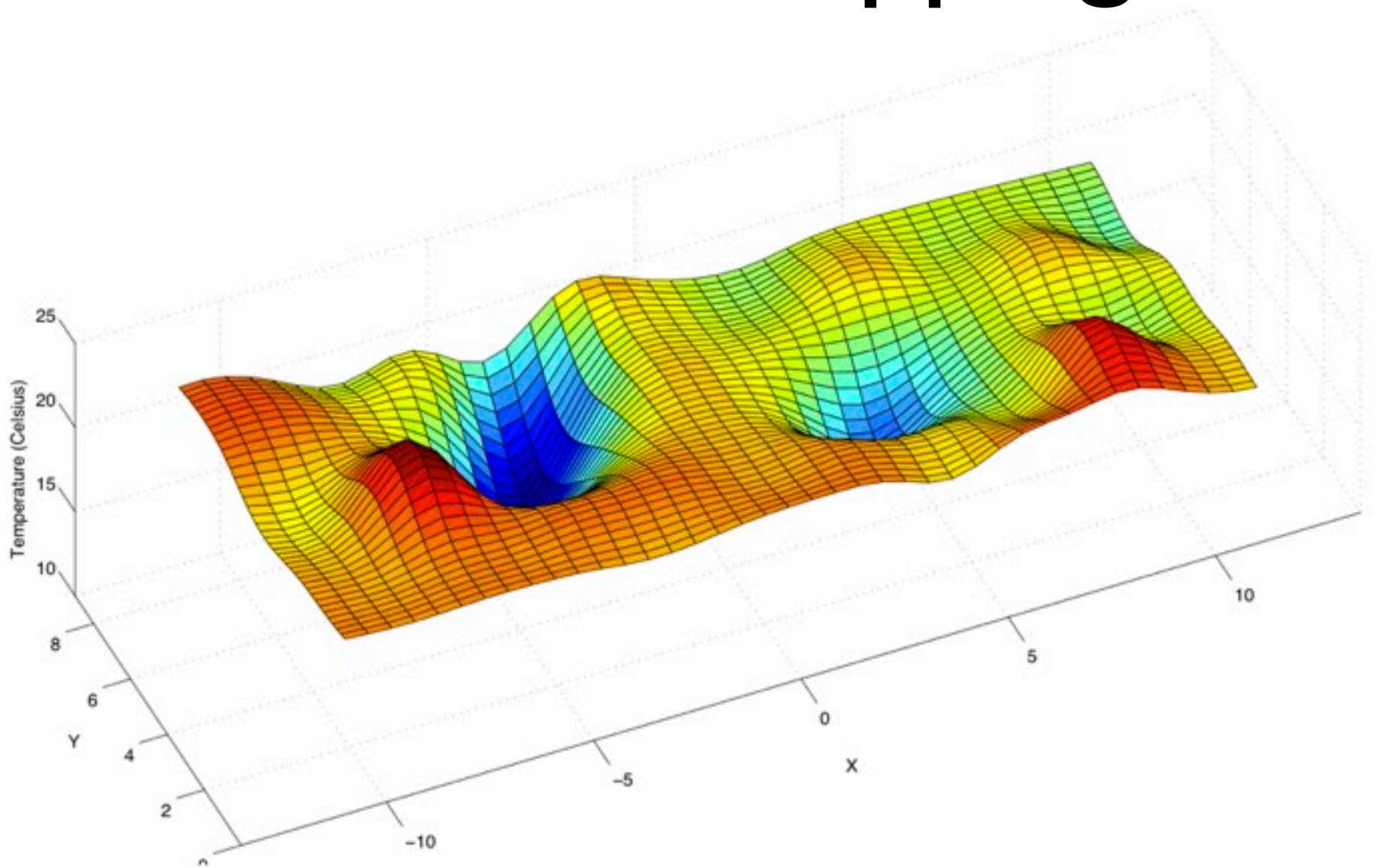




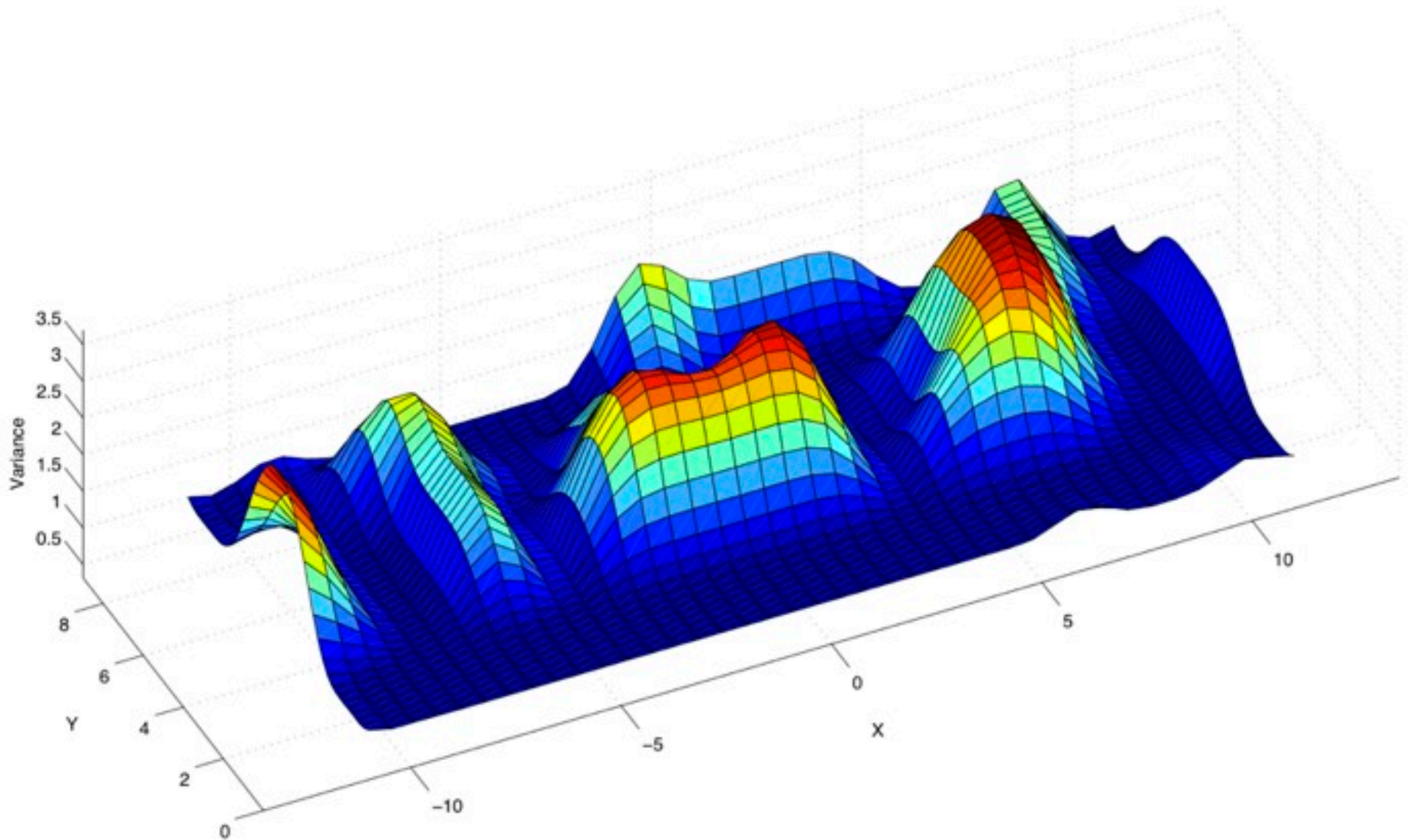
# Thermal Mapping



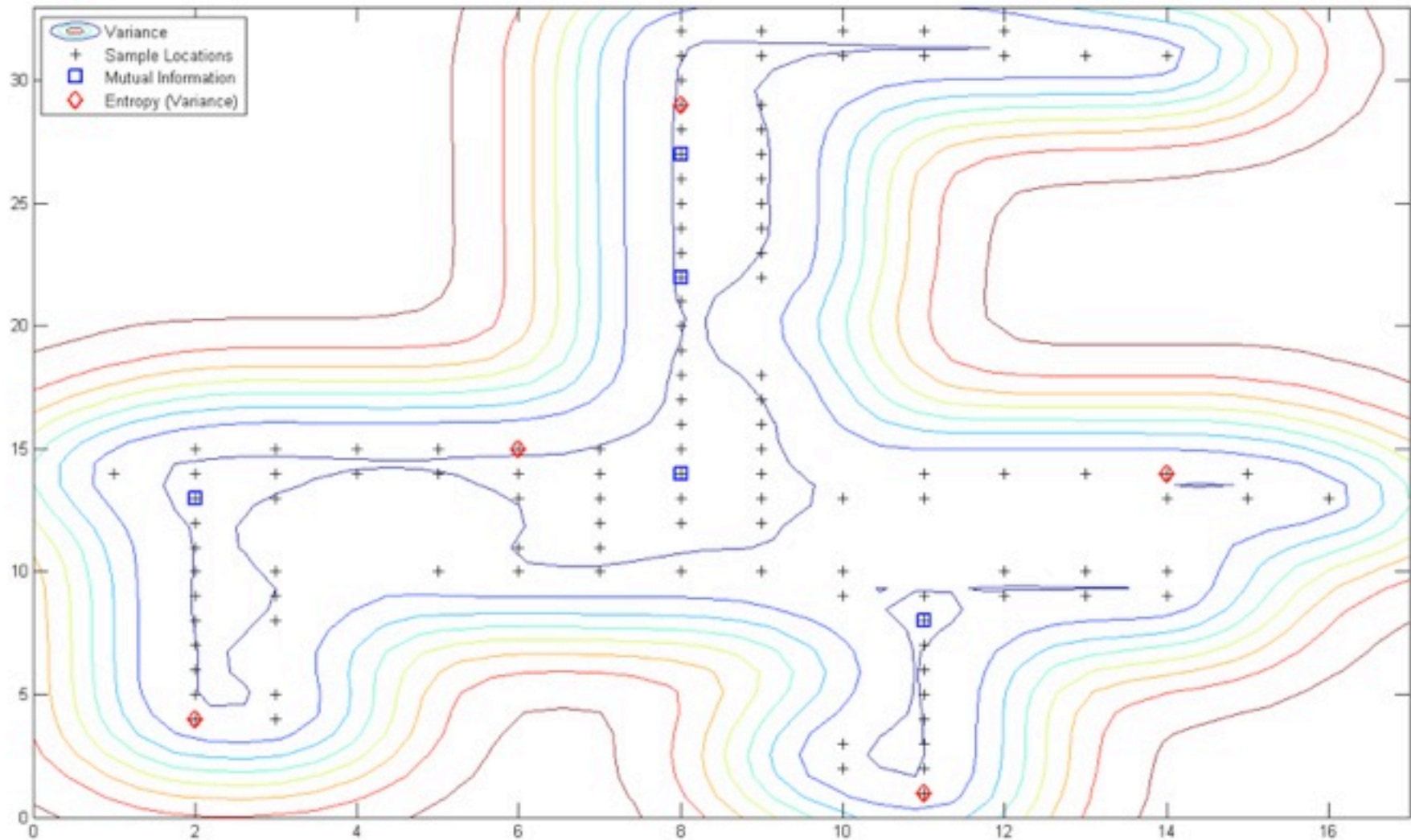
# Thermal Mapping



# Thermal Mapping



# Selective Sampling



# Summary

- Static sensors provide dense temporal resolution, but sparse spatial resolution
- Autonomous monitoring platforms provide an adaptive tradeoff between spatial and temporal density at a lower cost
- Data center monitoring and analytics provide a promising domain for robotics research and automation

# Thank You

- Canturk Isci, Jon Lenchner
- Jon Connell
- IBM Research

# References

- C. Guestrin, A. Krause, and A. P. Singh, “Near-optimal sensor placements in gaussian processes,” in Proceedings of the 22nd International Conference on Machine Learning, 2005
- A. Singh, A. Krause, C. Guestrin, W. Kaiser and M. Batalin, “Efficient planning of informative paths for multiple robots,” in Proceedings of the 20th International Joint Conference on Artificial Intelligence, 2007.