Reflex Tree

A New Computer and Communication Architecture for Future Smart Cities

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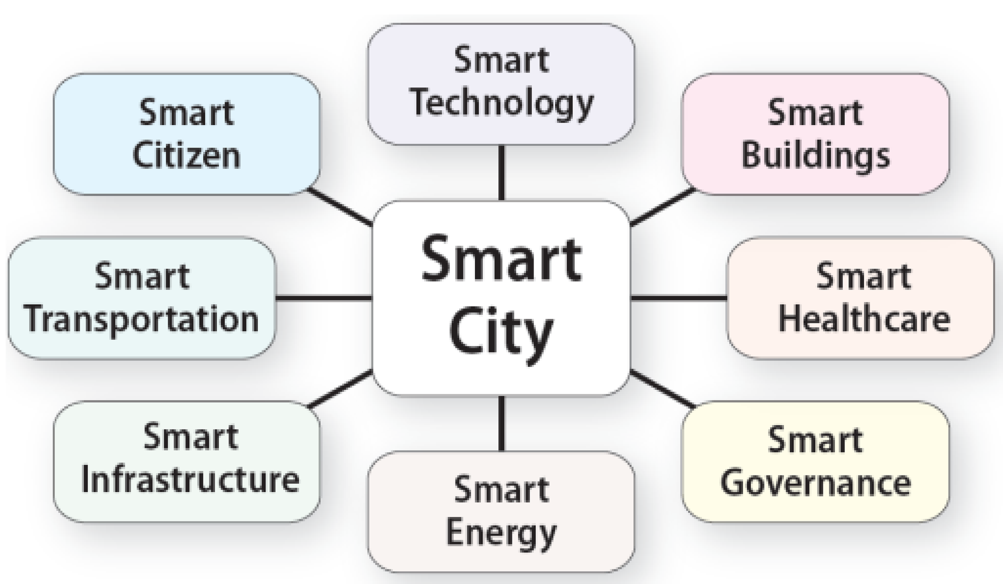
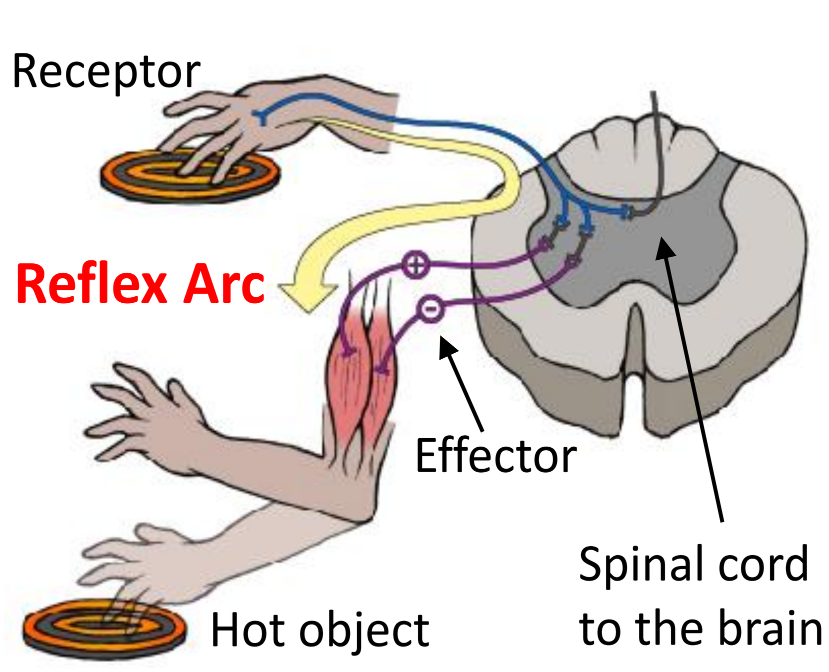
Summary

- We propose new computing and communication architecture, reflex-tree, with massive parallel sensing, data processing, and control functions suitable for future smart cities, an emerging concept with market worth of $3.3 trillion by 2025.

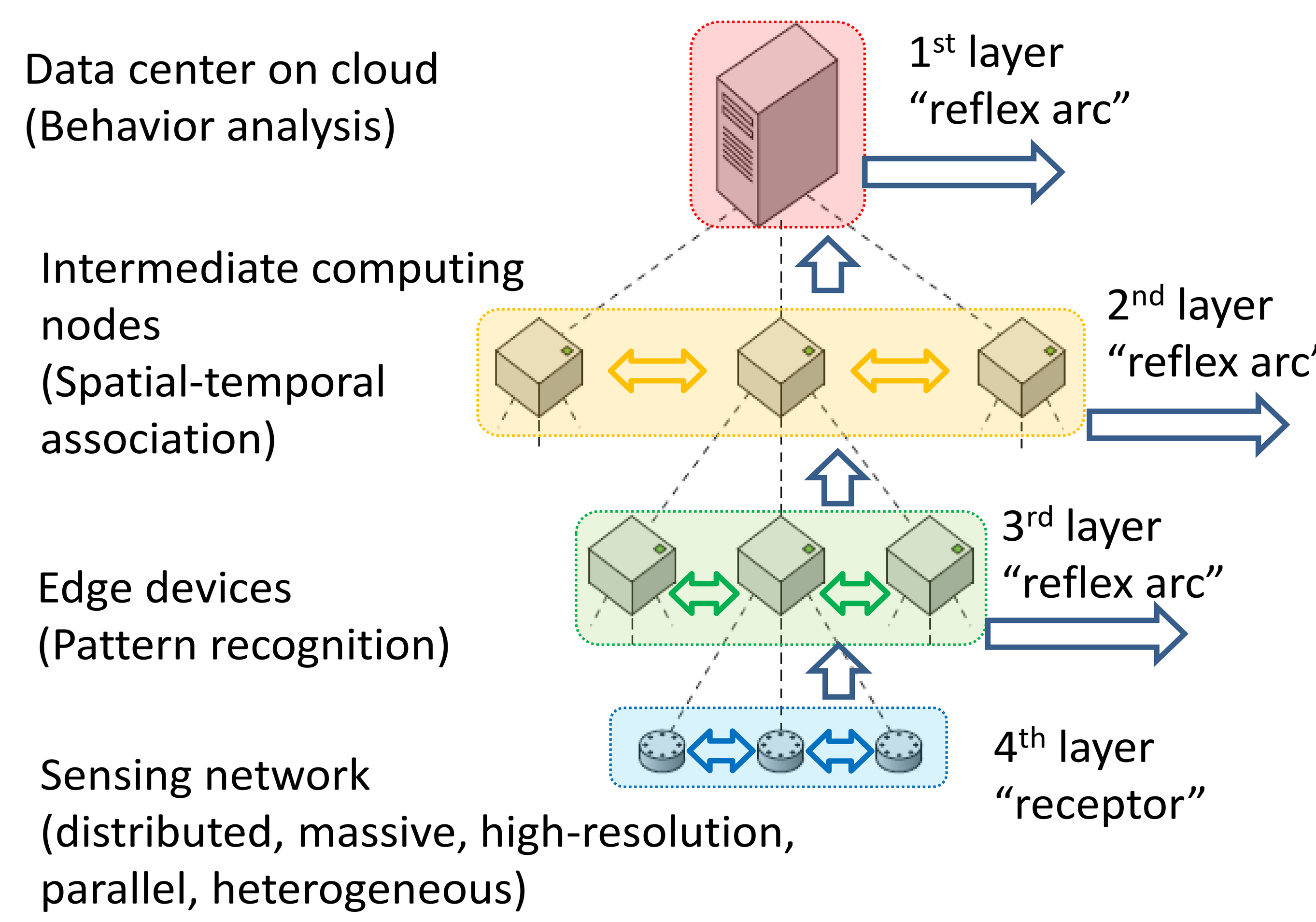


- The central feature of the proposed reflex-tree architecture is inspired by a fundamental element of the human nervous system – reflex arcs or, neuromuscular reactions and instinctive motions of a part of body in response to urgent situations. While the brain is the central controller of body activities, a local neural reflex arc is able to cause an individual to pull their hand away from a source of discomfort without the need for direct control from the brain.



- Our reflex-tree architecture mimics such human neural circuits—a massive amount of intermediate computing nodes, edge devices, and sensors work in a parallel and cohesive fashion to gather, process, and, most importantly, to react to data concerning critical infrastructure elements. This processed information is ultimately passed up a 4-level hierarchy to a centralized cloud system, providing the intelligence and control necessary to successfully manage future smart cities.

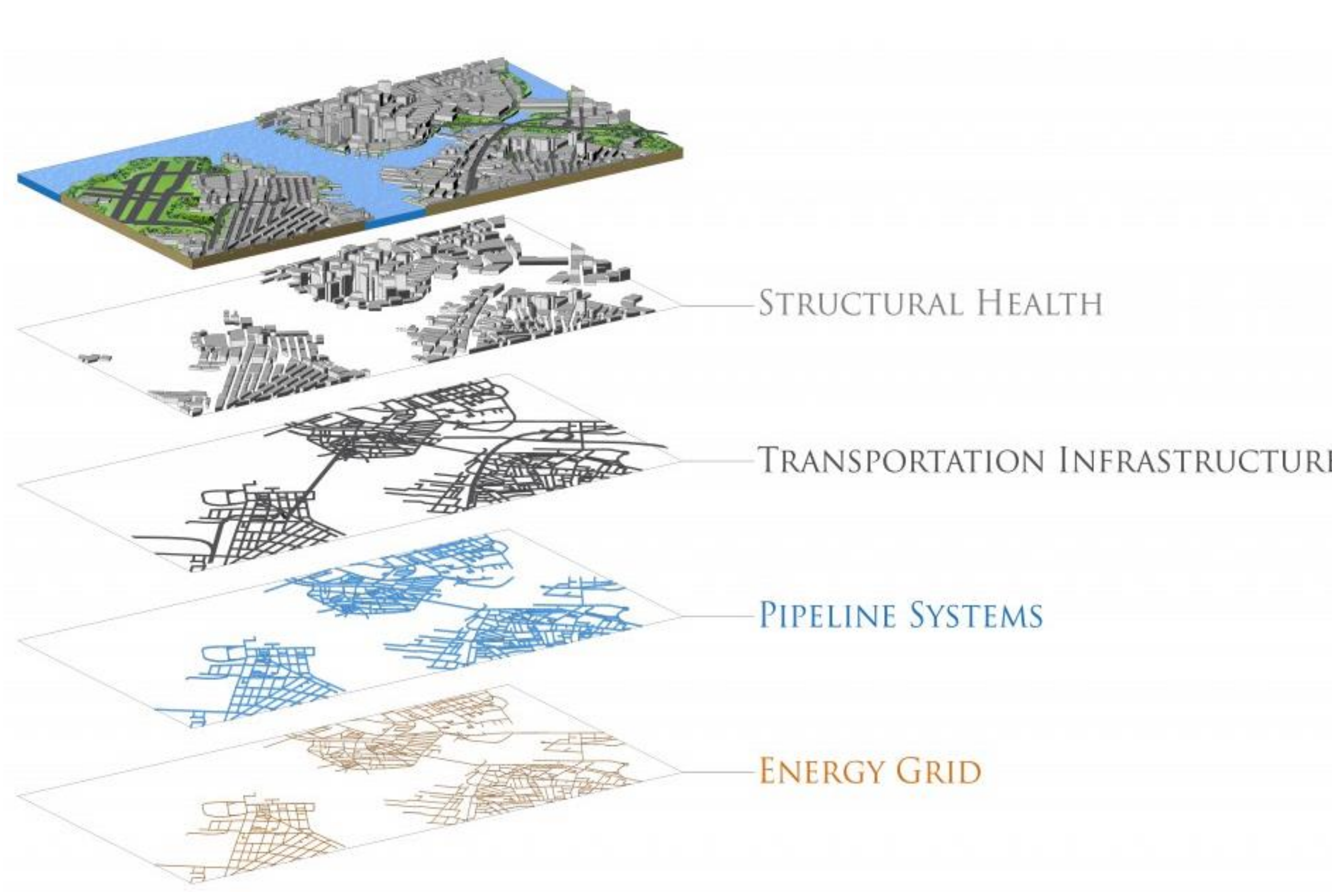
Intellectual Merits



- A novel fiber-optic sensing network provides distributed strain and temperature sensing with unprecedented spatial/temporal resolution (~mm, > 50 Hz) enabling massive, parallel, real-time sensing.
- Complementary machine intelligence algorithms will be developed, which will provide accurate control decisions via a multi-layer adaptive learning, spatial-temporal association, and complex system behavior analysis.
- Hardware architectures and software run-time environments will be proposed and developed that are specifically tailored to our new computing algorithms for the reflex-tree system.

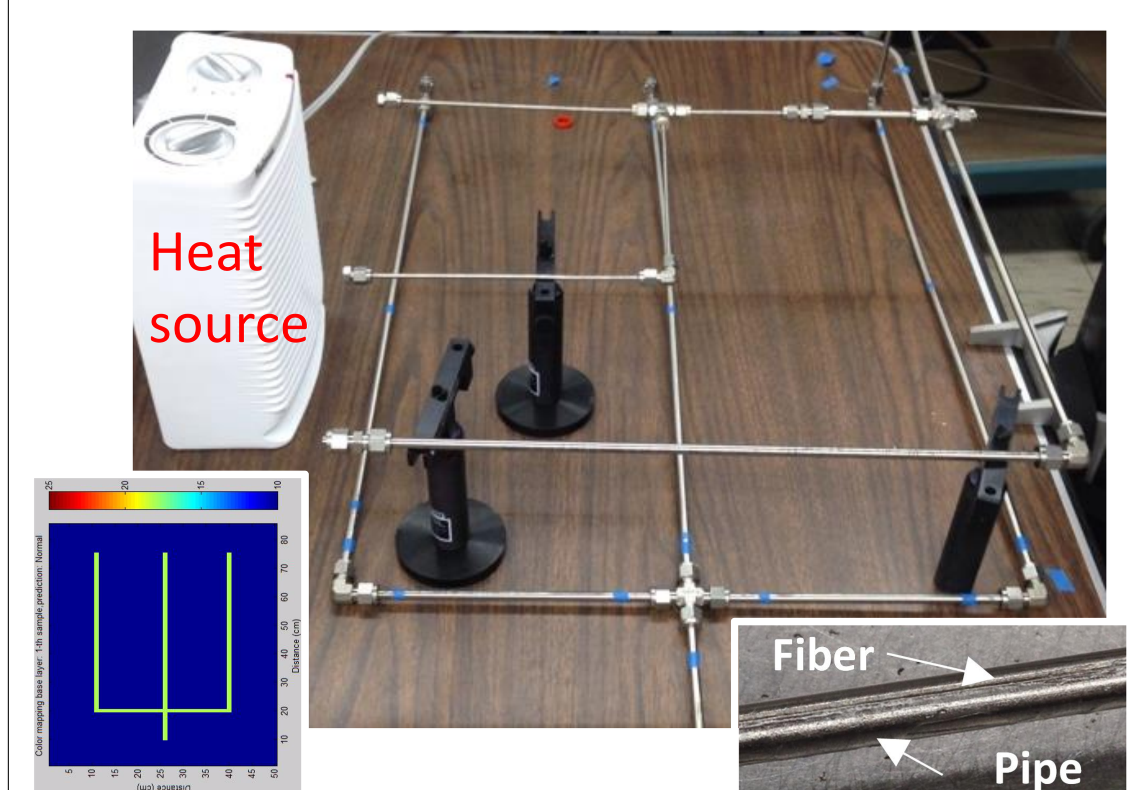
Broader Impact

- This study will have broad impacts on the sustainability, safety, and human welfare of urban areas as it represents a leap for future smart cities.
- The scientific foundation and engineering framework built by this project will pave the way for enhanced monitoring and management of critical smart city infrastructure, from gas/oil pipelines, water management, communication networks, and power grids, to public transportation and healthcare.



Results

- To demonstrate the feasibility and performance of the reflex-tree architecture, a proof of concept prototype is constructed utilizing a miniaturized, laboratory-scale municipal gas pipeline system.



- The prototype incorporated a complete 4-level reflex-tree—a distributed fiber-optic sensing network deployed along the pipelines, edge devices performing data classification using parallel hidden Markov model (HMM), intermediate nodes performing massively-parallel spatial and temporal machine learning, and the cloud as the root node running sophisticated parallel behavioral analysis and decision making tasks.
- Distributed sensor performance metrics:
  - Spatial resolution < 1 cm
  - Temperature resolution < 1 °C
  - Total length of coverage > 100 m
  - Update rate > 2 Hz
- Predication results from edge devices:
  - 13 different heating patterns/sources
  - 10 training data from each class
  - 6 sub-areas on the current system
  - 4 different algorithms developed
  - Best predication performance 91.4%
  - Worst predication performance 90.1%

Acknowledgements

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