Resilient Computation in Hierarchical Heterogeneous Systems

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Whole-System Perspective

A tesseract of interconnected and interdependent systems

Technological
Human
Environmental

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Cloud Analysis

Advanced forms of detection and prediction are needed to control the system.

Cloud data analytics

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IoT Layer

Key Enabler: Flow of information from IoT devices

Wireless and Wireline Communication Infrastructure

IoT devices

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Centralized Approach: Degraded resiliency

- Dependency on another system
- Single point of failure
- Increased attack surface

Congestion, jamming, attacks (DoS), Disconnection

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Cascade of Systems

Hierarchical System

Cascade of
• Networks
• Sensors
• Computation devices

Cloud datacenter

Edge datacenter

Edge devices

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Classification

Global Classifier

Trained to achieve high accuracy
• In any context
• Using all features

Complex separating surface obtained through a very complex classifier

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How do we make the system resilient: Replication

- Resilient to failures (network, devices)
- Lower-layers’ nodes may not be able to run the classifier
- Local view: feature subsampling

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Hierarchical Classification

Pipeline of Classifiers

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Sequence of classifiers of decreasing complexity

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Hierarchical Classification

Pipeline of Classifiers

Sequence of classifiers of decreasing complexity

- Reduced bandwidth (reduced risk of congestion, more resilient to attacks)
- Fast (approximated) control if pipeline fails

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Hierarchical Classification

Approximation

Simpler classifiers may not perform well enough

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Training on the Fly

Global Classifier

Complexity comes from heterogeneity of samples

Complex separating surface obtained through a very complex classifier

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Context

Context-induced distributions of samples may lead to context-specific good classifiers

“Local” distributions

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Online Classifier Training

- Network of collaborative classifiers
- Higher layers’ classifiers tune the parameters of the low layers’ classifiers
- Classifiers follow the dynamics of the system
- Optimal - low complexity - localized filtering and control

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In mobile health care systems, the framework proposed cannot be implemented.

Cloud Decision rule
\( \delta: \mathbb{Z} \mapsto \{0, 1\} \)

Node Decision rule
\[
\begin{align*}
\delta(x, \mu) & \geq \mu, \\
x & \in \tilde{X}_0
\end{align*}
\]

\[
\begin{align*}
\tilde{\theta}_{t+1} & = \theta_t - \gamma_t J(z_{t+1}, \theta_t, \mu_t) \nabla_{\theta} f(x_{t+1}, \theta_t), \\
\tilde{\mu}_{t+1} & = \mu_t + \gamma_t J(z_{t+1}, \theta_t, \mu_t), \\
\text{vec}(\theta_{t+1}, \mu_{t+1}) & = \mathcal{H}_D(\text{vec}(\tilde{\theta}_{t+1}, \tilde{\mu}_{t+1})), \\
J(z, \theta, \mu) & \triangleq \hat{I}_{\mu}^{(1)}(f(\chi(z), \theta)) - I_1(z)
\end{align*}
\]

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Examples

```latex
\begin{align*}
Z^{(0)} & \quad Z^{(1)} \\
\quad & \\
f(x, \theta) = \mu
\end{align*}
```
Conclusions

**Adaptive Hierarchical Computing**

- Reduced bandwidth usage
- Reduced response time
- Increased accuracy

**Other applications**

- Urban IoT systems
- “Personalized” sensing for Mobile Health Care
- Autonomous UAVs

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