Towards a Science of Cyber Physical Systems Design

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Overview

• Introduction (CPS & application)
• Characteristics of physical process
  (self-similarity, non-stationarity)
• Use data to identify the characteristics
• Present a novel physics inspired model
Introduction

- Cyber physical systems (CPS) consist of networks of embedded computation and communication devices, as well as sensors.
- CPS need to be dependable, safe, reliable, efficient, real-time, and secure.
- CPS help us define new communication and interaction protocols.
CPS Application

• Traffic monitoring
• Predict natural disasters & terrorist attacks
• Detect oil/gas transportation pipes
• Help to build smart building

(environmental friendly and energy efficient)
CPS Pyramid
CHARACTERISTICS OF PHYSICAL PROCESSES

• Self-similarity

Self-similarity is defined as the property of objects to look the same under the operation at various scales in space or time.
• a) Power spectral density of short range communication in local area network (LAN) established via wireless links between moving vehicles.
• c) Power spectral density of the packet received signal strength obtained in a wireless network.
CHARACTERISTICS OF PHYSICAL PROCESSES

• Non-stationarity

Nonstationarity of a process implies that its probability distribution
b) Multifractal spectrum of information transaction events (i.e., sent / received packets) in a LAN where communication connectivity is established via wireless links and access points in an urban environment
• The CPS workloads typically consist of a mix of many types of data.
• Variable $x(t)$ denotes the CPS workloads.
A NEW FORMALISM

\[ P(x,t \mid \alpha) = P(x_0,t_0) + \int_{0}^{\infty} dt' \int_{0}^{\infty} w(x-y,t-t') P(y,t' \mid \alpha) dy \]

- denotes the conditional probability of finding the system in a particular state \( x \)
- is the initial condition
- is the kernel probability capturing the dependency of the evolution of probability \( P(x,t \mid \alpha) \) on the memory of the stochastic process \( x(t) \).
NEW FORMALISM

\[ P(x,t) = P(x_0,t_0) + \int_{\alpha_{\min}}^{\alpha_{\max}} b(\alpha) \, d\alpha \int_0^t \frac{(t-t')^{(\alpha-1)} \, dt'}{\Gamma(\alpha)} \int_0^\infty v(x-y) P(y,t' | \alpha) \, dy \quad (2) \]

\[ \int_{\alpha_{\min}}^{\alpha_{\max}} b(\alpha) \frac{\partial^\alpha P(x,t | \alpha)}{\partial t^\alpha} \, d\alpha = \int_0^\infty v(x-y) P(y,t) \, dy \quad (3) \]

\[ \int_0^\infty v(x-y) P(y,t) \, dy = a_1 f_1(x-1) P(x-1,t) + a_2 f_2(x+1) P(x+1,t) - \]

\[ - [a_1 f_1(x) + a_2 f_2(x)] P(x,t) + \int_0^\infty \frac{\gamma(x-y)}{h(y,t)} P(y,t) \, dy \quad (4) \]

\[ \int_{\alpha_{\min}}^{\alpha_{\max}} b(\alpha) \frac{\partial^\alpha P(x,t | \alpha)}{\partial t^\alpha} \, d\alpha = \frac{\partial^2}{\partial \alpha^2} \left[ (a_1 f_1(x) + a_2 f_2(x)) P(x,t) \right] - \]

\[ - \frac{\partial}{\partial x} \left[ (a_1 f_1(x) - a_2 f_2(x)) P(x,t) \right] + \int_0^\infty \frac{\gamma(x-y)}{h(y,t)} P(y,t) \, dy \quad (5) \]
Figure 5. Graphical representation of transition probabilities assumed to govern the evolution of the stochastic process $x(t)$. In the absence of uncertainty, the transition probability from state $(x-y, t')$ can be neglected and the noise coefficient $\gamma(x-y)=0$.
Conclusion

• Introduction (CPS application & characteristics)
• Present new view of CPS design in which shown how complex characteristics of CPS workload can be modeled via a fractal-based master equation.
• Formulate the control problem which can be particularized to various CPS design problems (resource allocation, task scheduling, mapping)
Questions?
Thank you~