USC Viterbi School of Engineering

Ming Hsieh Department of Electrical Engineering

Multicore Platforms for Real-Time Analytics in Closed-Loop Cyber-Physical Systems: Design Challenges and Opportunities

Paul Bogdan

University of Southern California

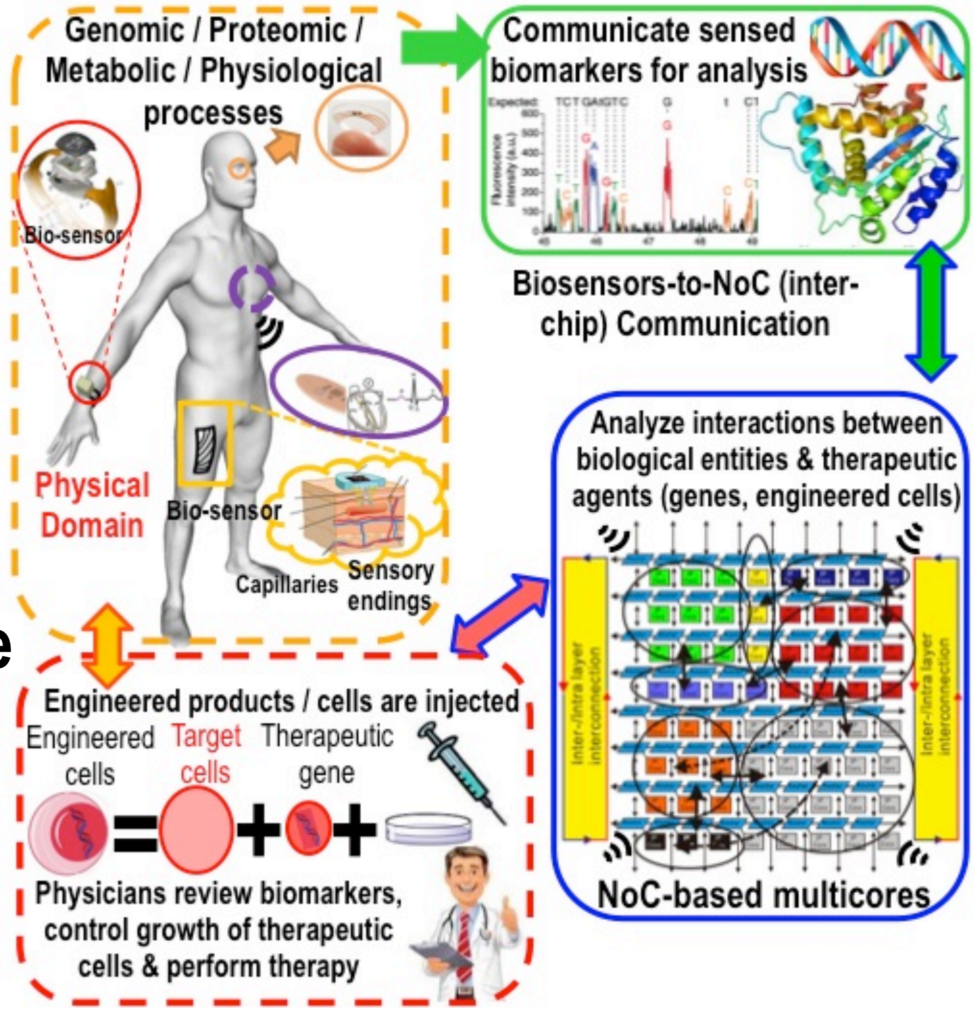
Workshop on Big Data Analytics in CPS: Enabling the Move from IoT to Real-Time Control

April 13th, 2015

USC

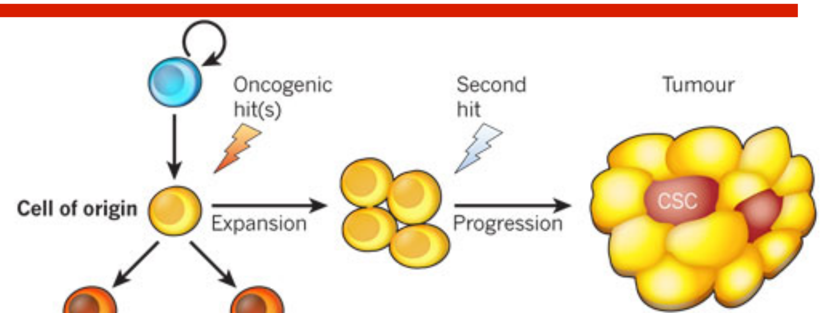
Outline

- ❑ **Challenges in modern medicine**
- ❑ **CPS premises**
  - ❑ Sensing of genomic processes
  - ❑ Sensing of proteomics
  - ❑ Sensing of metabolic processes
  - ❑ Sensing of physiological processes
- ❑ **CPS for personalized medicine**
  - ❑ Definition of multicore-based CPS
  - ❑ A mathematics of goal-oriented self-organization optimization for multicore-based CPS
- ❑ **Conclusions**

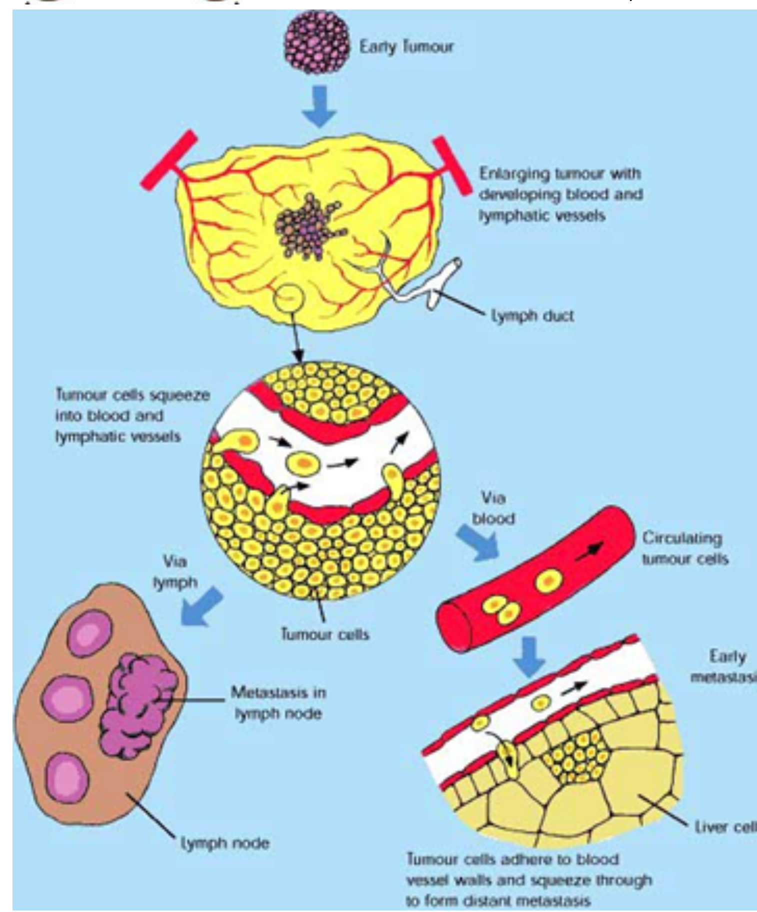


Challenges in Modern Medicine

- **Detection of silent progression & migration of diseases**
  - cancer cells or blood clots that can cause strokes
- **Drug and gene determination and delivery to areas of the human body which are not easily accessible**
- **Multi-drug resistance due to inappropriate & insufficient drug delivery compared to disease progression**

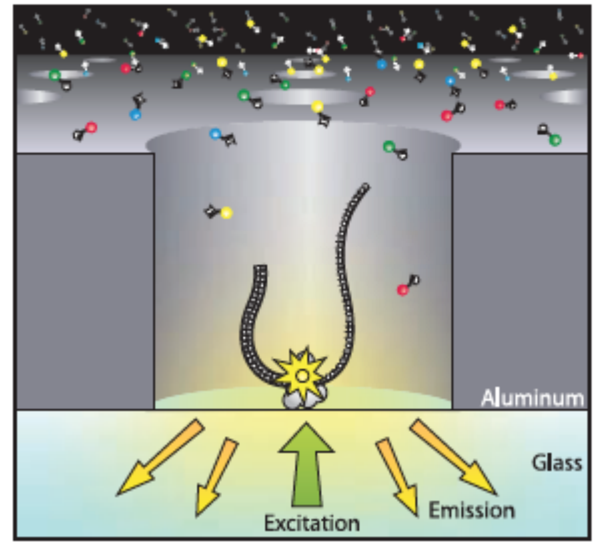


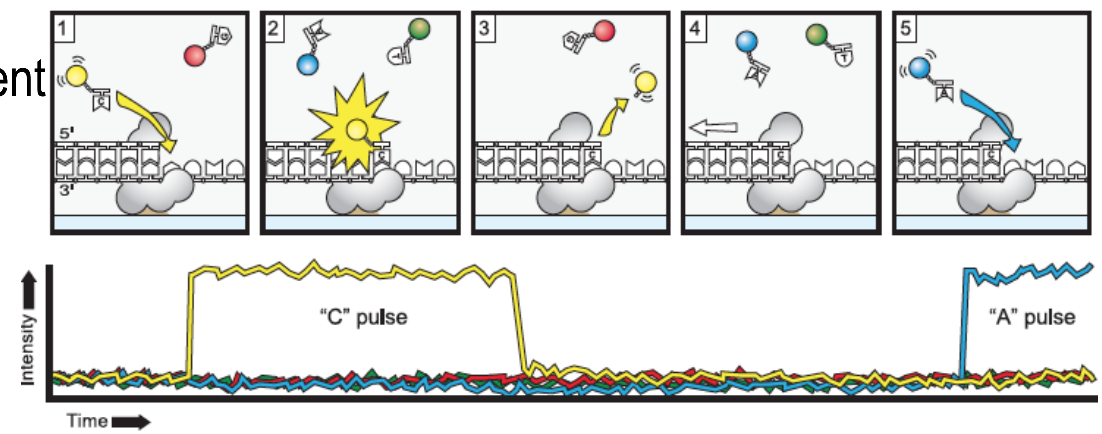
Visvader, Nature 2011



Sensing of Genomic Processes

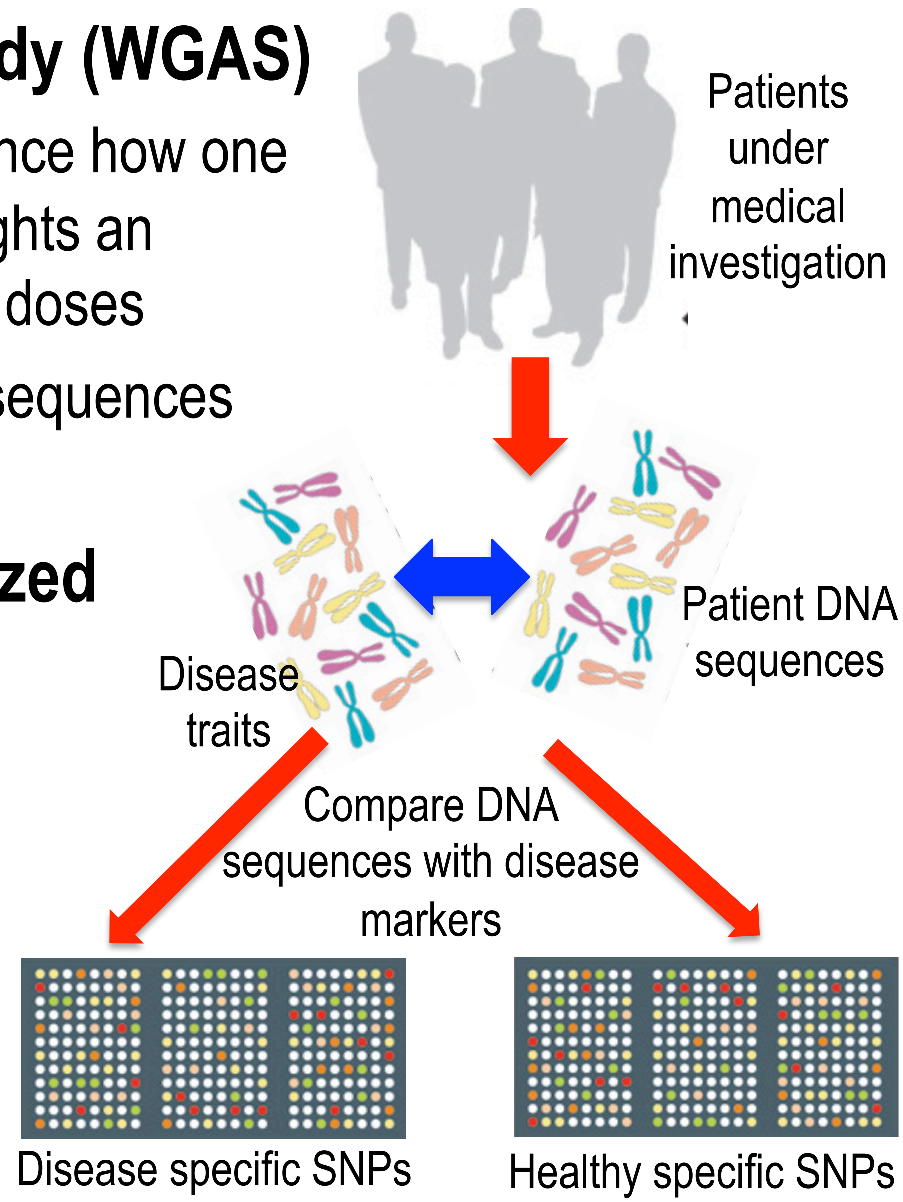
- **Real-time DNA sequencing technology**
  - Single-molecule measurements (SLMs) help with detecting genomic transient (rare) events in real-time for living cells
    - Genomic processes (transcription, translation, splicing)
    - SLMs enable the measurement of a large number of genome sequences in parallel
  - Dimethyl-sulphate sequencing (DMS-seq)
    - Facilitates the analysis of the structure-function relationships of RNAs





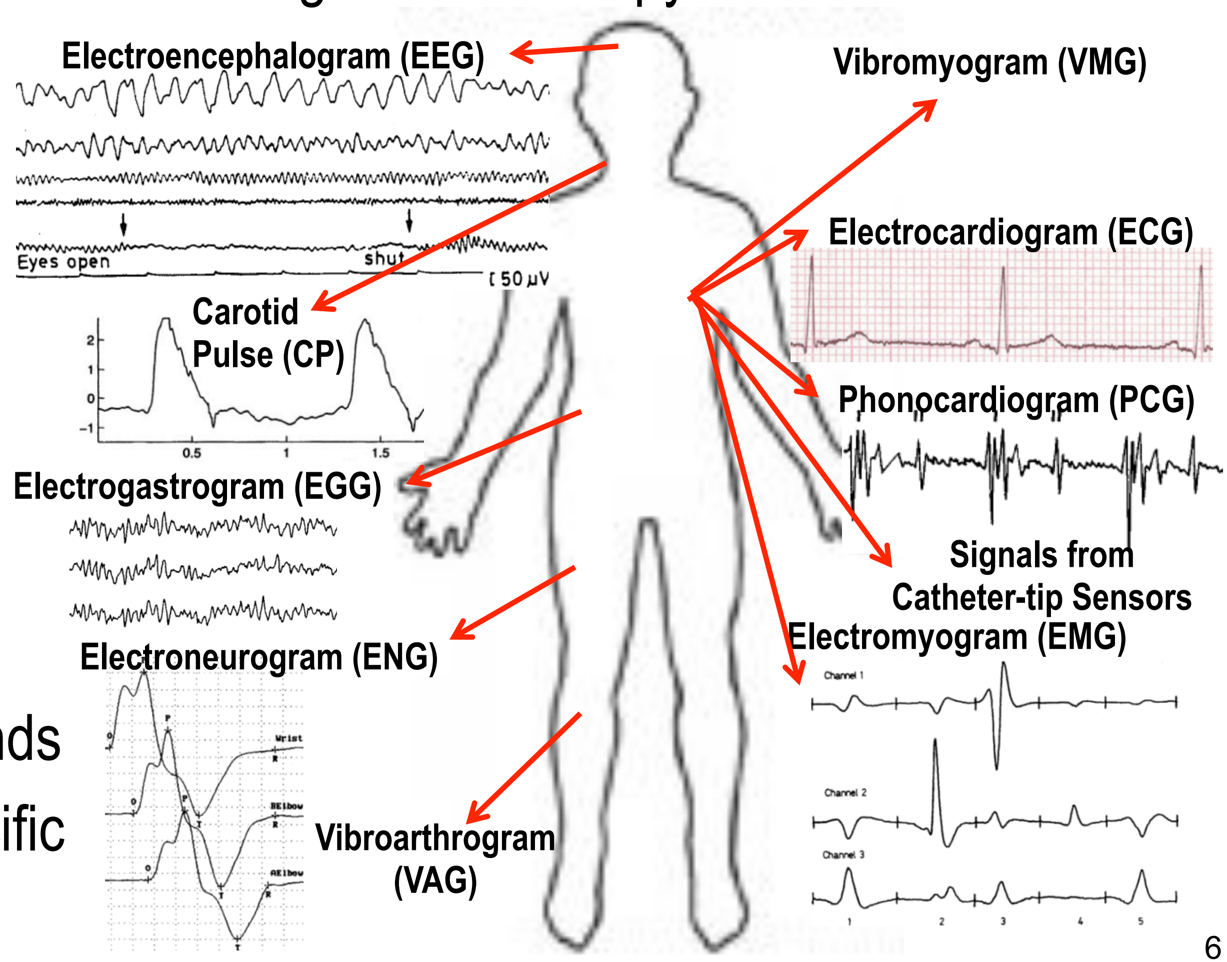
Complexity of Mining Genomic Processes

- **Whole-genome association study (WGAS)**
  - Variations in DNA sequences influence how one human body develops a disease, fights an infection, reacts to various drugs or doses
  - Detect associations between DNA sequences and diseases / infections
- **Solve many correlated generalized least-square (GLS) problems**
  - Complexity
    - $O(m \times n \times p^3)$ floating point operations
  - Large heterogeneous datasets
    - Read / process / write TBs of data
  - Parallelism issues
    - Data / tasks partitioning, task mapping



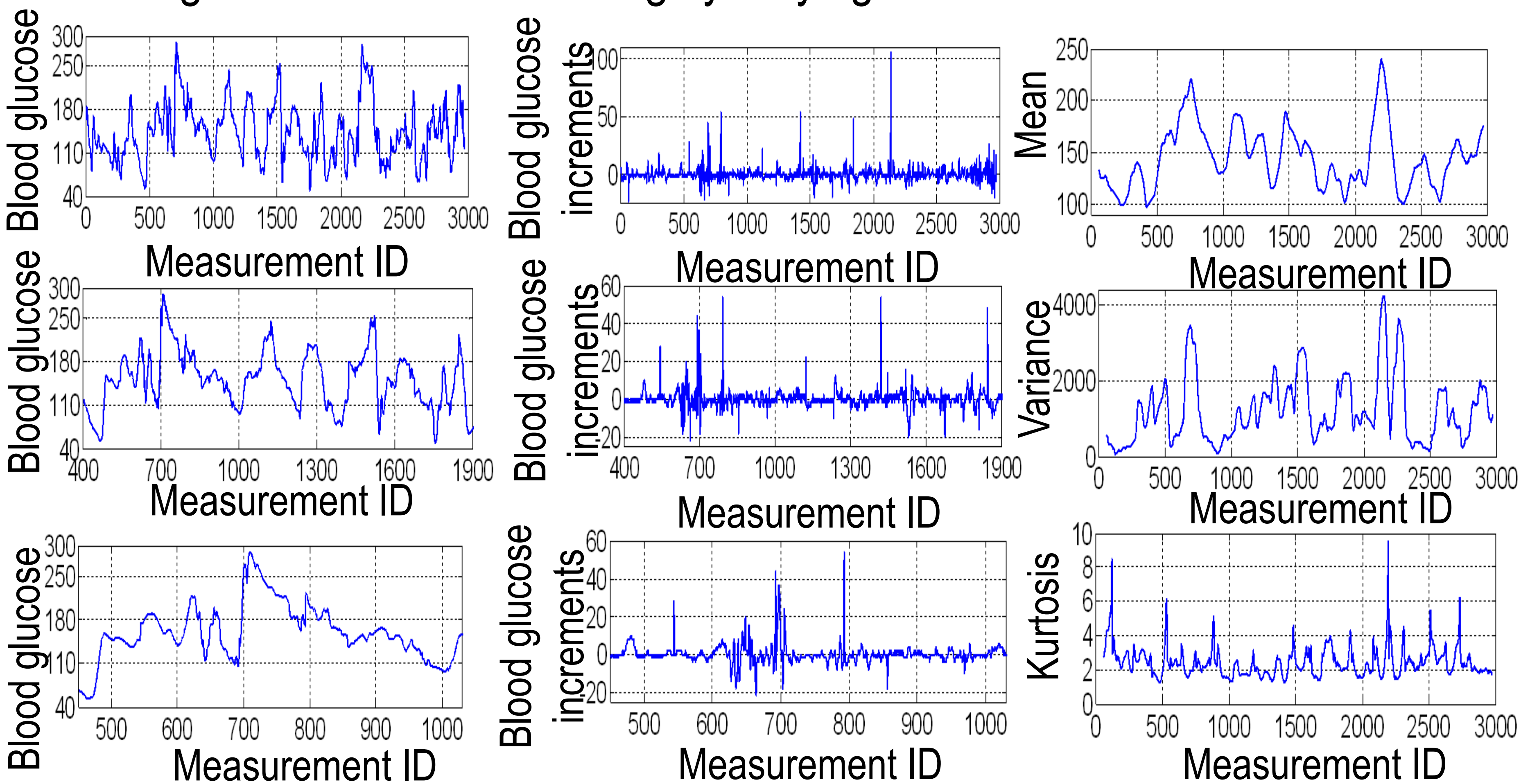
Sensing of Physiological Processes

- **Physiological processes**
  - Encompass signatures of dynamical interactions among human organs
  - Represent the basis for medical diagnosis & therapy
- **Real-time monitoring**
  - Heart-rate
  - Blood glucose
  - EEG signals
- **Mining physiological complexity**
  - Detect abnormalities
  - Estimate & predict trends
  - Patient-nonlinear-specific control



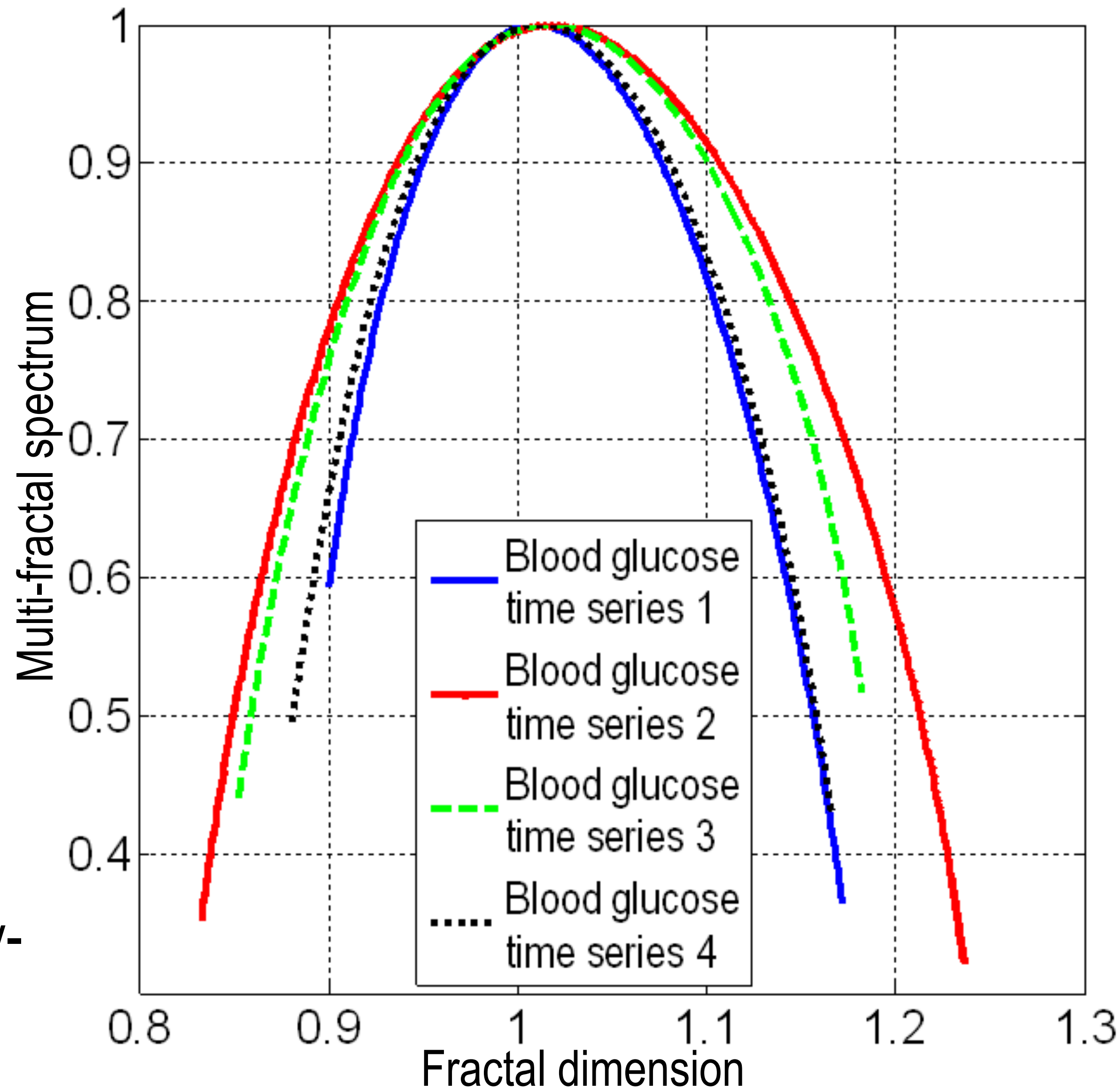
Complexity of Biological Processes (I)

- **Blood glucose exhibits a complex dynamics**
  - Higher-order statistics is highly varying over time



Complexity of Biological Processes (II)

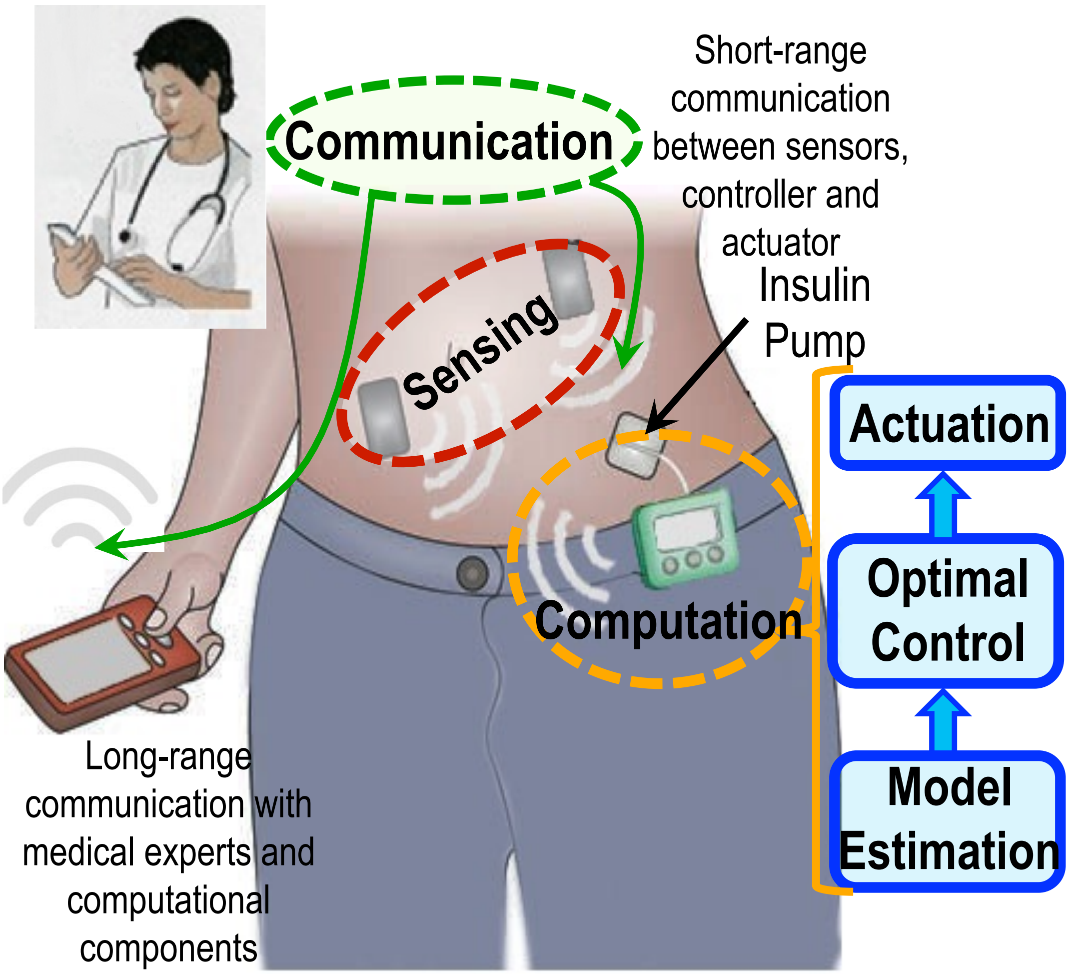
- **Physiological processes exhibit multi-fractal characteristics**
  - Being healthy means richer / wider multi-fractal spectrum
  - Being sick means narrower multi-fractal spectrum
  - Linear models can lead to poor control & quality-of-life physiological adaptation



Ghorbani and Bogdan, CODES+ISSS 2013.

Artificial Pancreas: A CPS Case-Study

- **Determine trends & control blood glucose variation**



- **Find *optimal insulin amount***

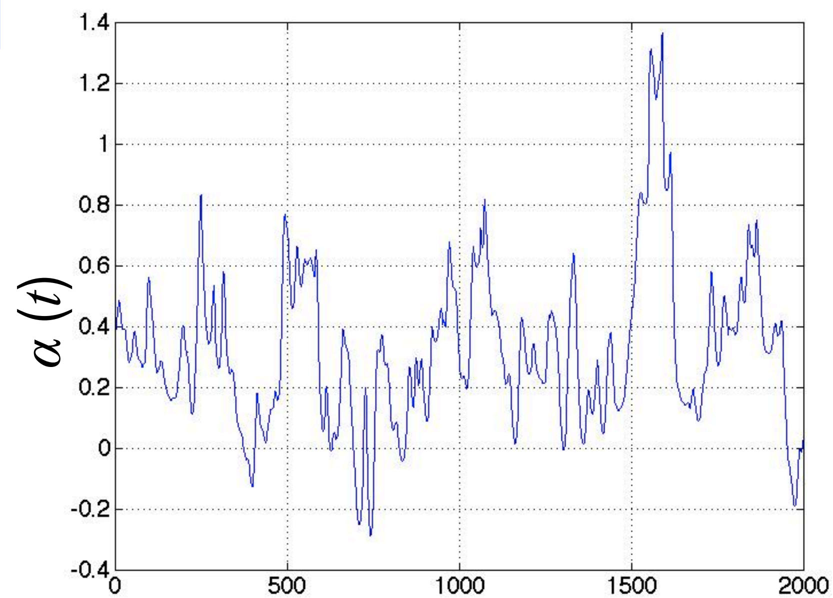
$$\min_{u(t)} \int_0^{t_f} \left\{ \left(g(t) - g(t)_{ref}\right)^2 + w\left(u(t) - u(t-1)\right)^2 \right\} dt$$

- subject to

$$\frac{d^{\alpha(t)} g(t)}{dt^{\alpha(t)}} = a(t)g(t) + b(t) + c(t)u(t)$$

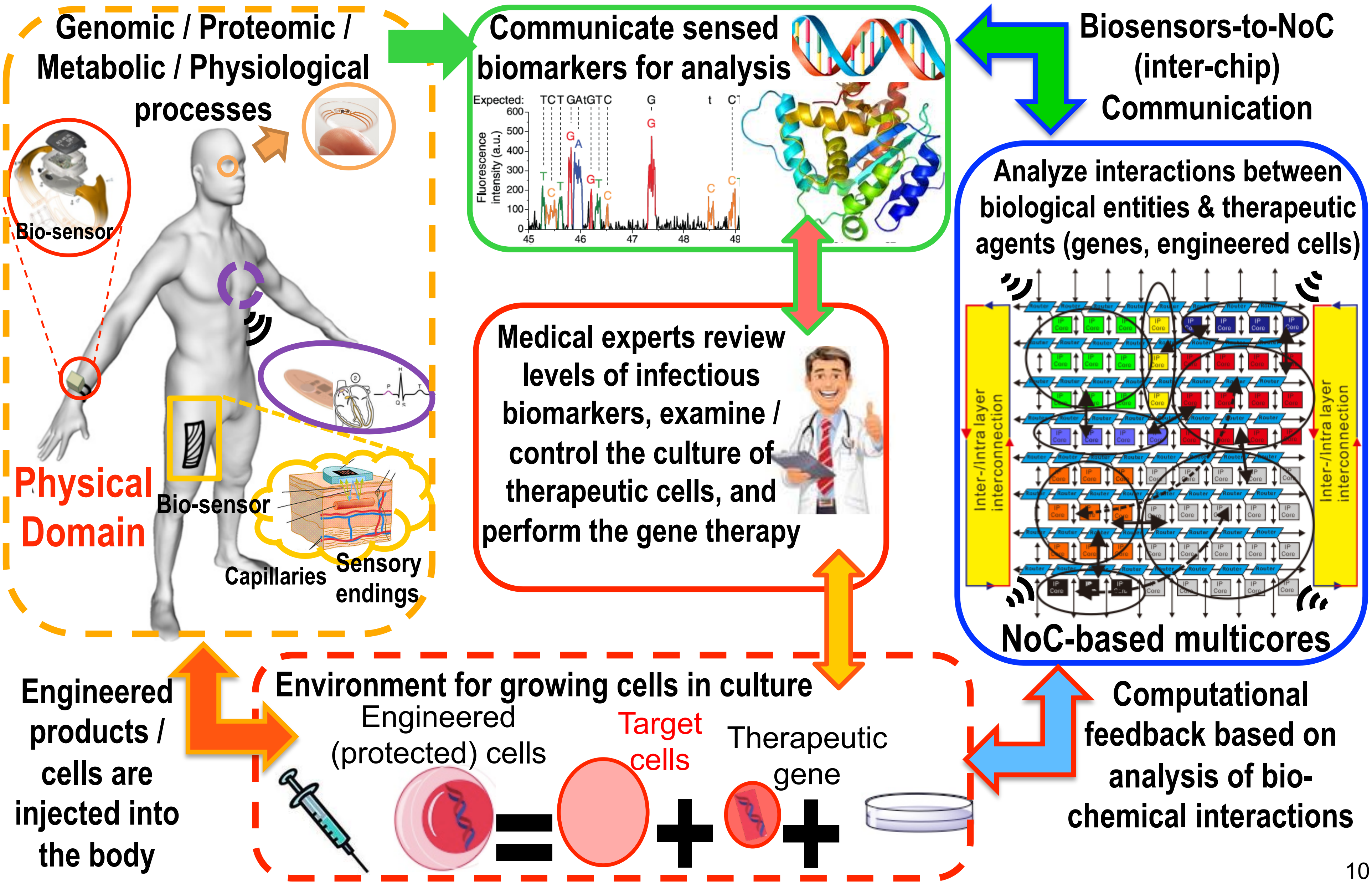
$$u^{\min} \le u(t) \le u^{\max}$$

$$g^{\min} \le g(t) \le g^{\max} \quad g(t=0) = g_0$$

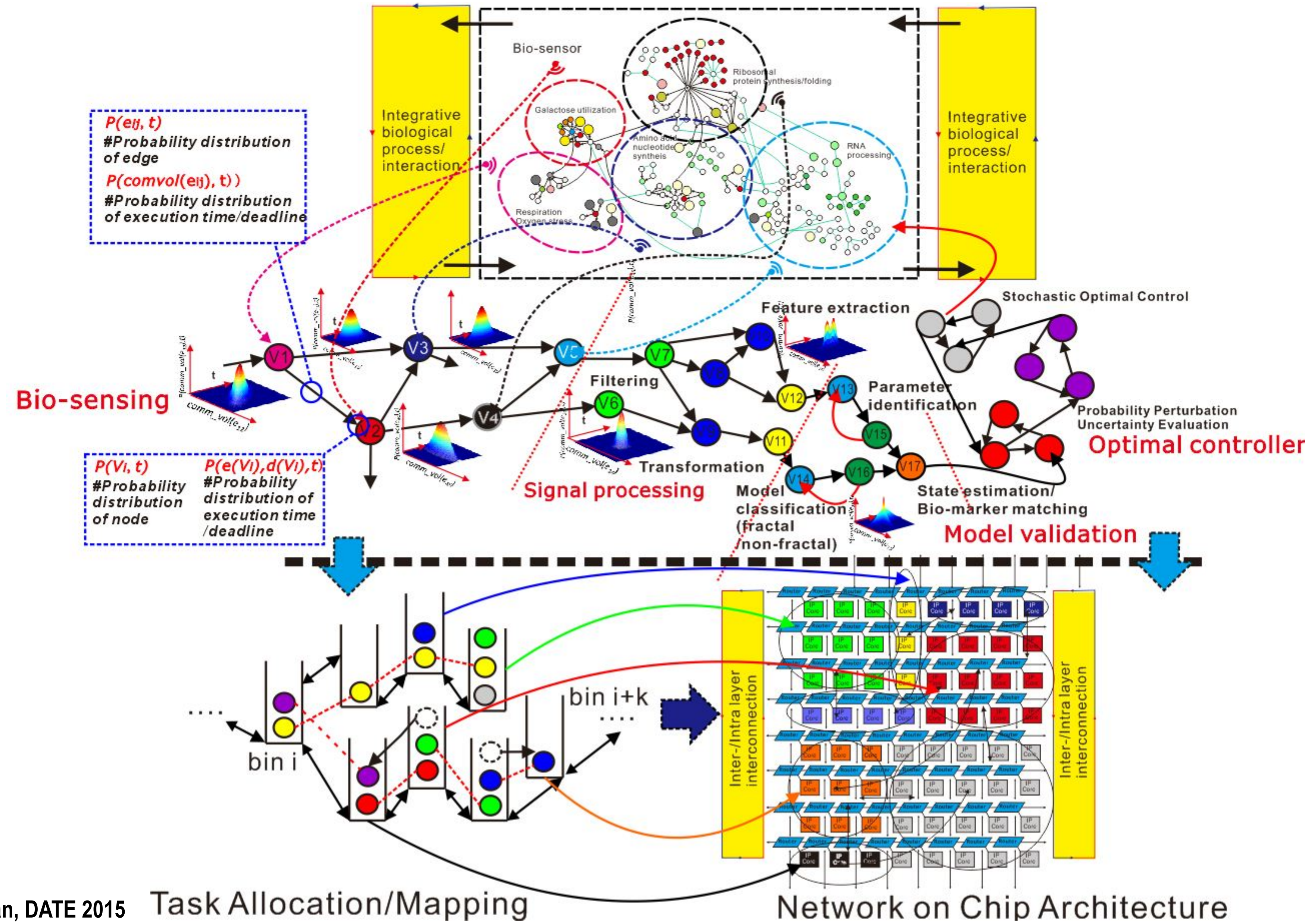


Ghorbani and Bogdan, CODES+ISSS 2013

A CPS Approach to Personalized Medicine



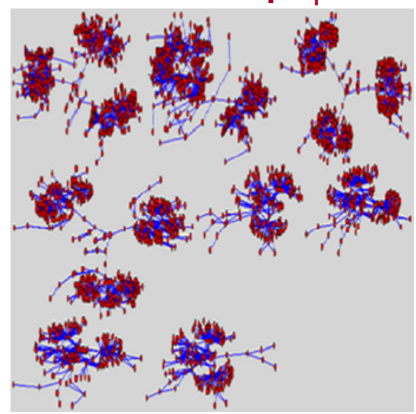
Cyber-Physical Integrative Task Graph



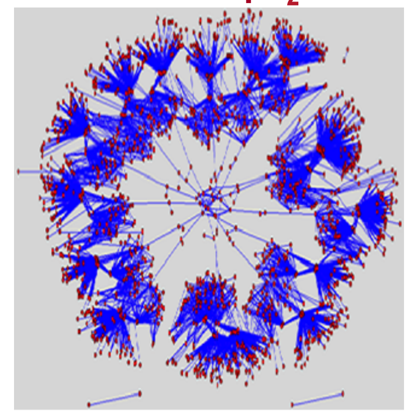
Challenges for Designing NoC-based CPS

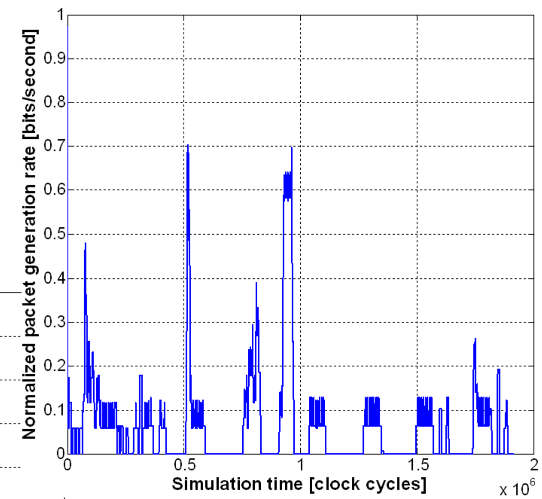
- **Mapping of highly dynamic / irregular application task graphs (ATGs)**
  - Task processing times are varying
  - Task communication requirements are heterogeneous & time varying
- **Transfer large volume of information efficiently (fast & small energy consumption)**
  - One application can require reading & writing TBs of data
- **Allocate resources to match ATG real-time requirements**

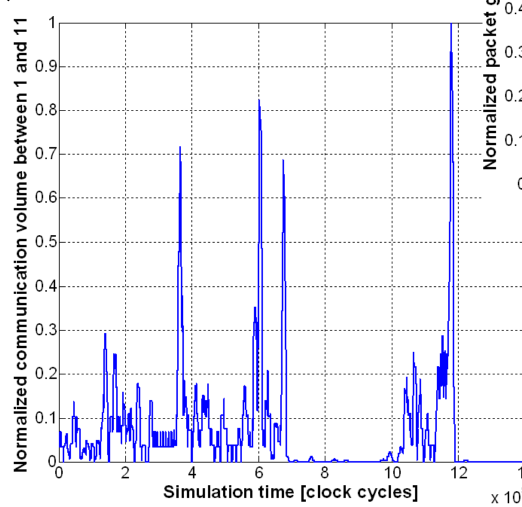
Time stamp t_1



Time stamp t_2

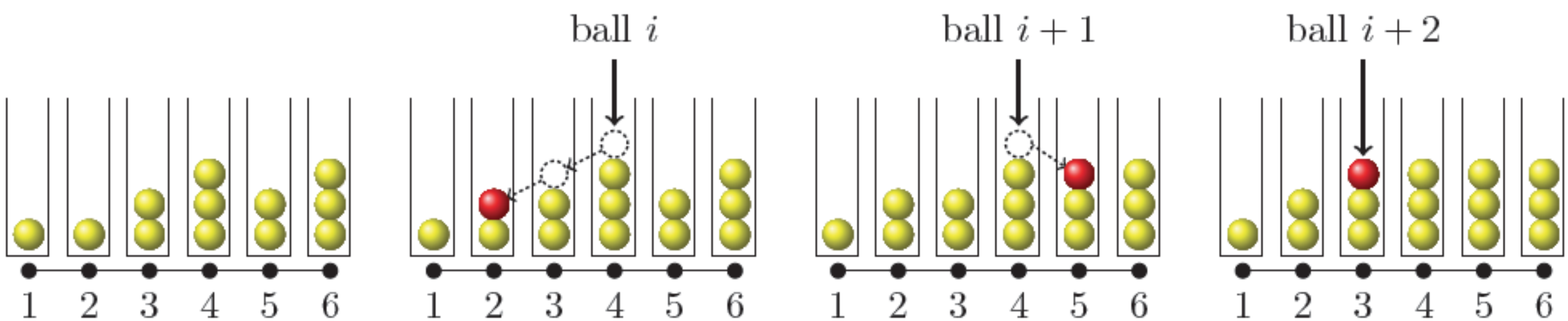






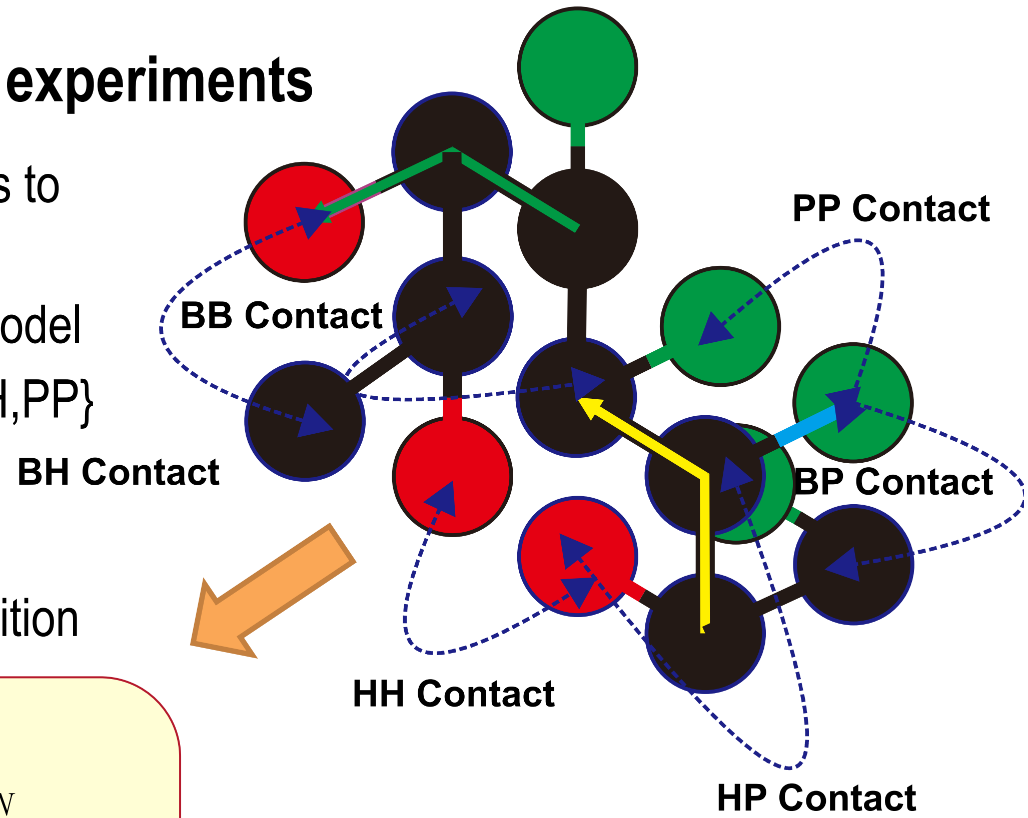
Balls into Bins: Correlation Allocation

- ***d*-choice random allocation of balls into bins**
  - Maximum load is $\Theta\left(\frac{\log\log n}{\log d}\right)$ [Azar et al., SIAM 1999, Karp et al., 1996]
- **Local search allocation**
  - At each step a ball (task) is born in a bin (network node) chosen independently and uniformly at random
  - Ball does a ***local search*** on ***graph*** & moves to an adjacent bin with smallest load
  - Local search ends into a local minimum when the ball reaches a node for which no neighbor has smaller load
  - Maximum load is $\Theta(\log\log n)$ on expander graphs



Protein Folding Analysis: A Case-Study

- **Protein folding problem in the experiments**
  - Protein final conformation corresponds to the minimal energy state
  - Fitness function based on 3DHPSC model
  - 6 contacts from set {BB,BH,BP,HP,HH,PP} are considered
  - Assume unity distance in cubic lattice
  - Penalty introduced for overlapped position



$$Fitness = H - N * PenaltyValue$$

$$H = e_{hh} \sum_{i=1, j>i+1}^{N} \delta_{r_{ij}}^{hh} + e_{hb} \sum_{i=1, j>i+1}^{N} \delta_{r_{ij}}^{hb} + e_{bb} \sum_{i=1, j>i+1}^{N} \delta_{r_{ij}}^{bb}$$

$$+ e_{bp} \sum_{i=1, j>i+1}^{N} \delta_{r_{ij}}^{bp} + e_{pp} \sum_{i=1, j=i+1}^{N} \delta_{r_{ij}}^{pp} + e_{hp} \sum_{i=1, j=i+1}^{N} \delta_{r_{ij}}^{hp}$$

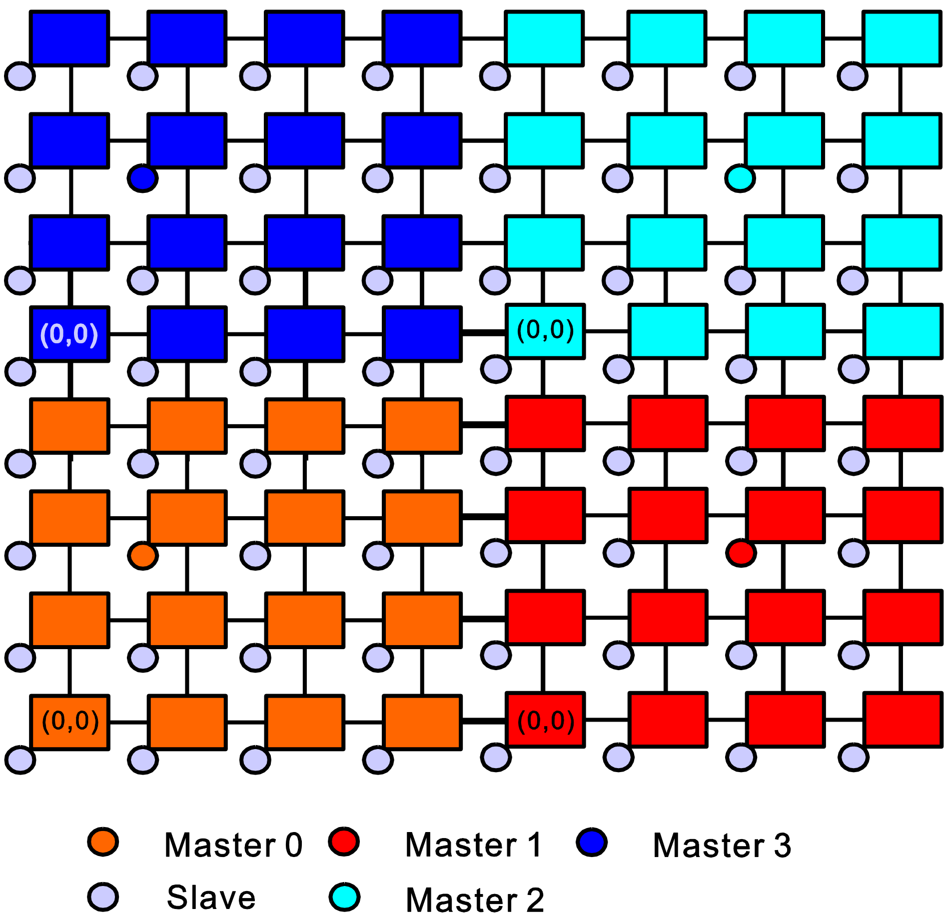
e_{lm} : Contact weight, l,m=B,H,P

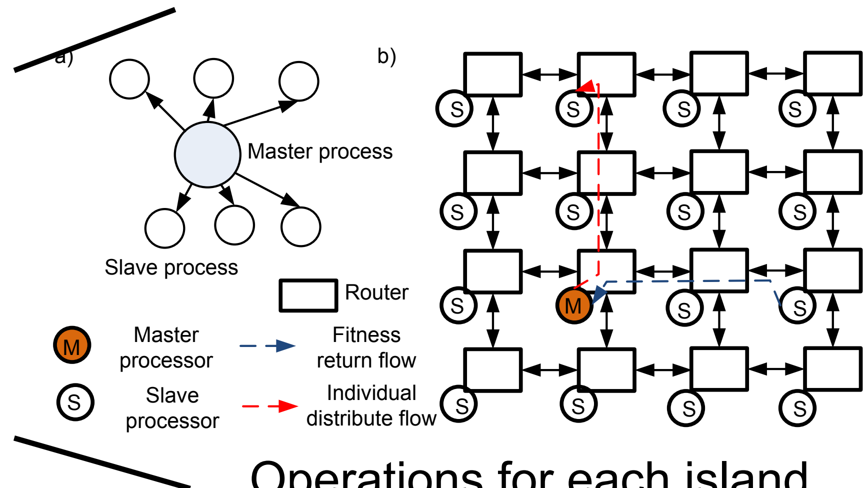
$$\delta_{r_{ij}}^{lm} = \begin{cases} 1 & \text{: if (i,j) contact exists} \\ 0 & \text{: otherwise} \end{cases}$$

Xue et al., DAC 2014

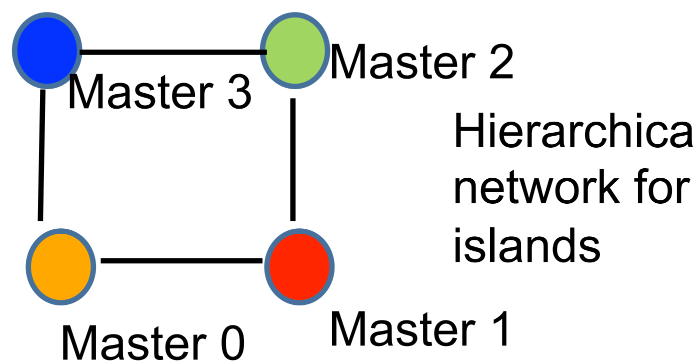
Naïve Island-based HPGA-NoC

- **Straight forward implementation**
  - Mapping multiple islands onto NoC





Operations for each island

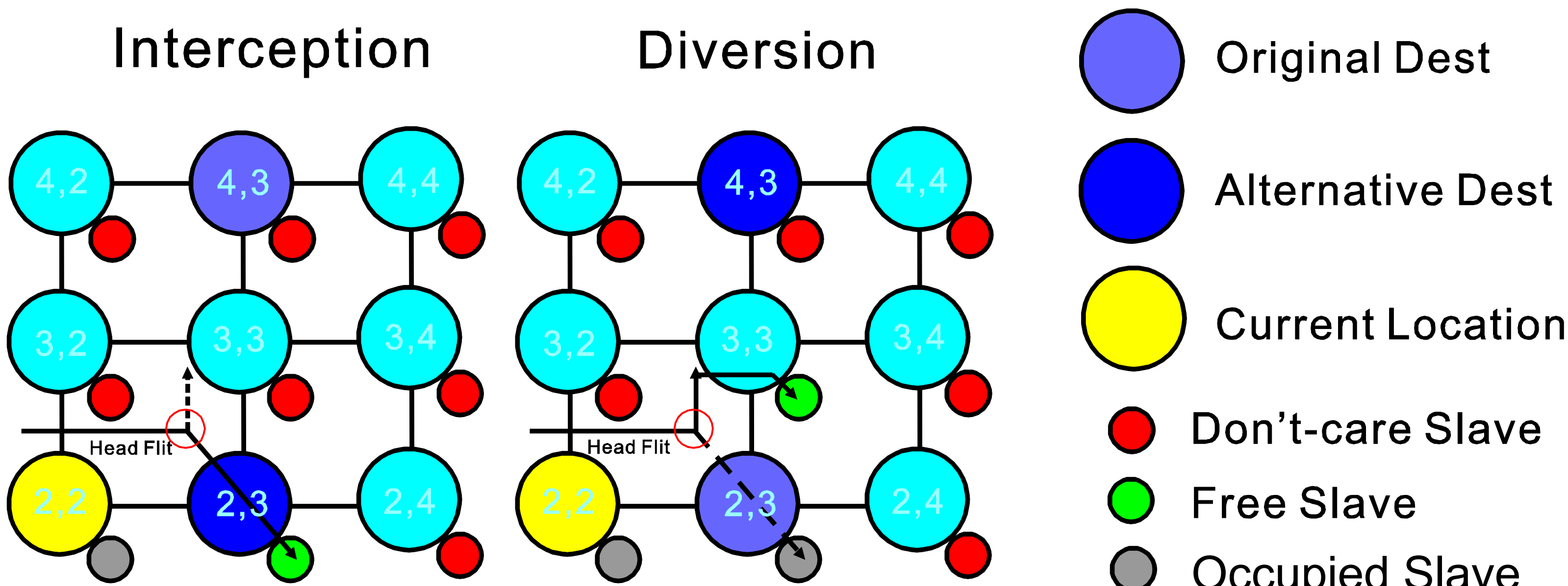


Migrations among the islands

Xue et al., DAC 2014

Self-Organized Resource Allocation & Routing

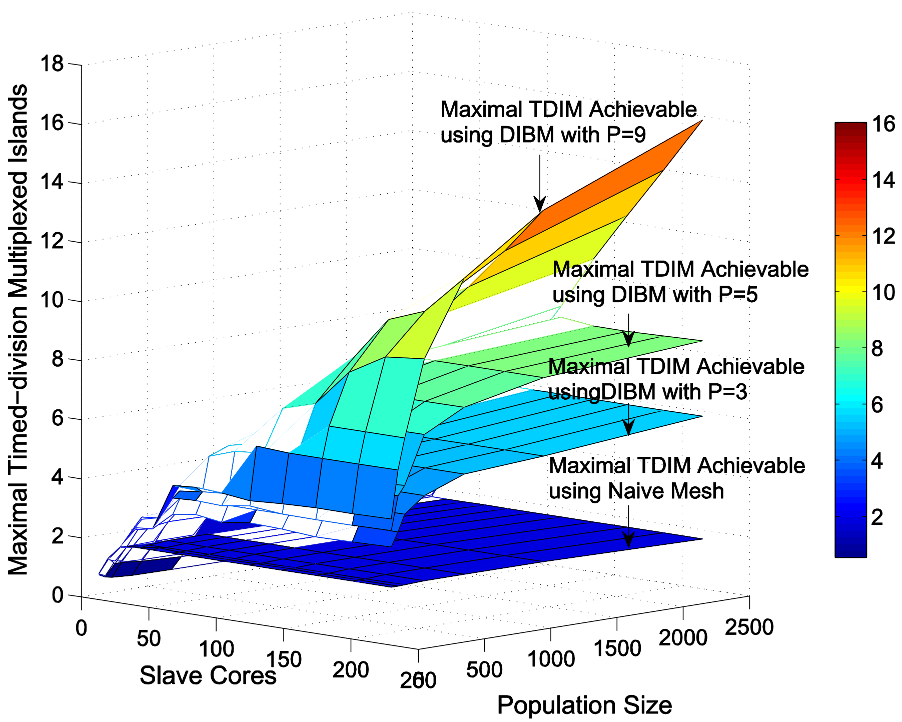
- Avoid extra delays when two masters distribute individuals simultaneously
- In the routing, packets (individuals) change the destinations adaptively

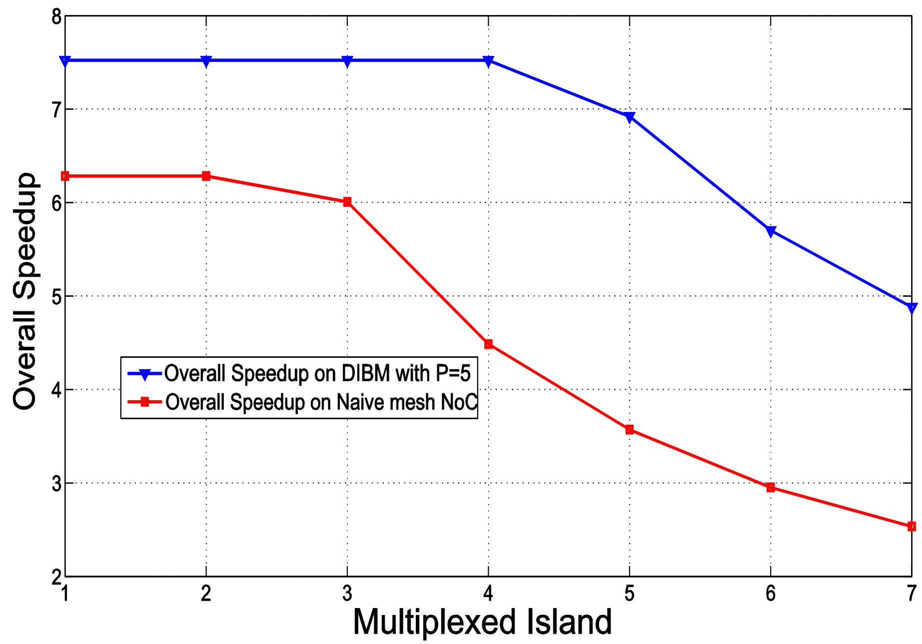


Xue et al., NOCS 2014

Self-Organized Resource Allocation - Benefits

- Maximum number of islands that can be multiplexed on a physical island
- Impact of island multiplexing number on the overall speedup performance





Xue et al., NOCS 2014

Conclusions and Credits

- **Self-organized inspired approaches prove beneficial for particular cases but**
  - Require parameter tweaking from one configuration to another which is unacceptable for real-time scenarios
  - Do not necessarily guarantee achieving the best solutions because do not exploit the existing information
- **Construct a mathematical theory of goal-oriented self-organization inspired optimization**
  - Learn and exploit the information structure
  - Discover and estimate cost functions at run-time
  - Design node-to-node interactions to enforce fast convergence

National Science Foundation
WHERE DISCOVERIES BEGIN

Thank you!

USC Viterbi School of Engineering

More info at http://ceng.usc.edu/cps/