Distributed Sensor Coordination for Advanced Energy Systems

NETL Kickoff Meeting

Dec. 15, 2009

PI: Dr. Kagan Tumer

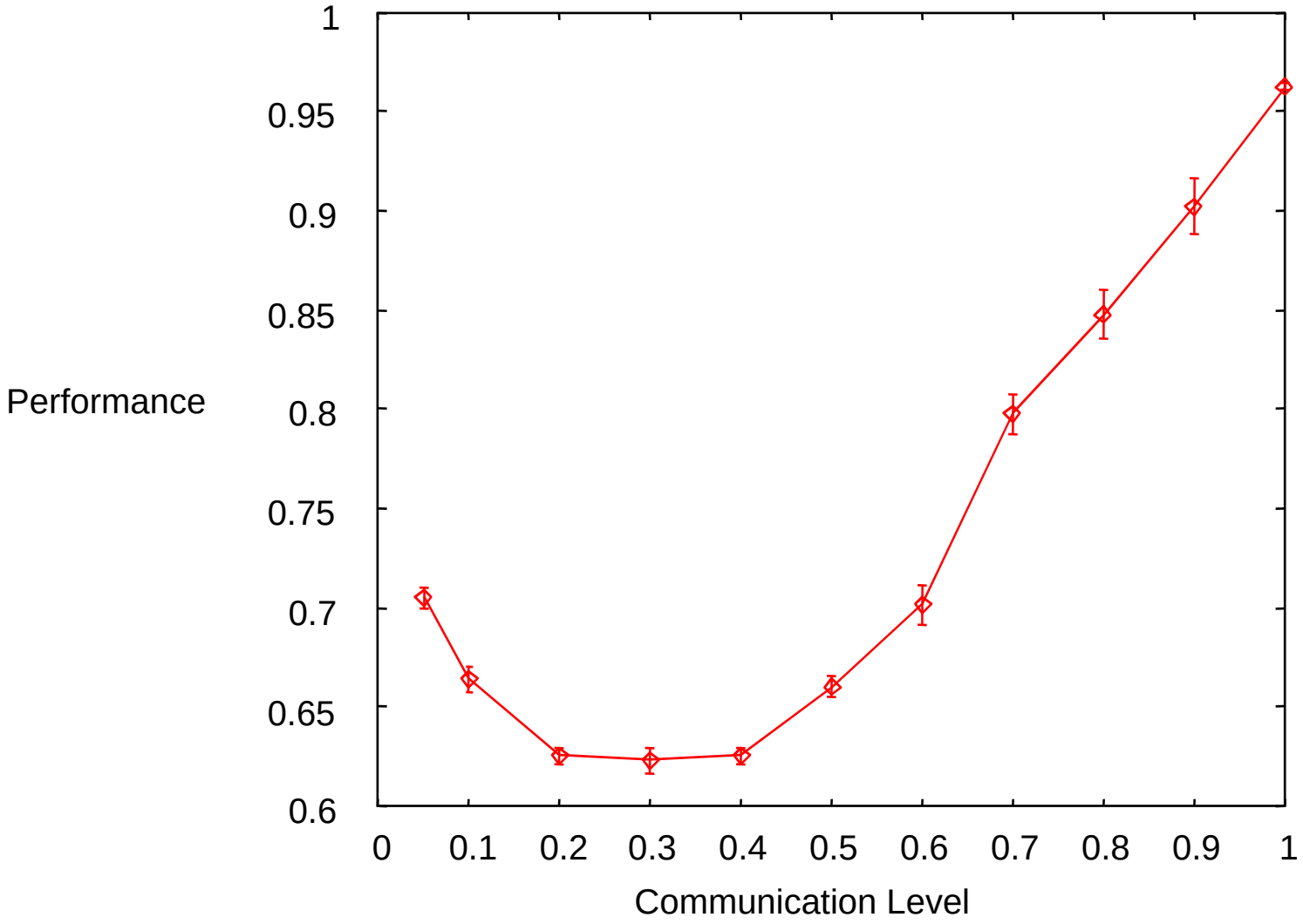
Presented by: Dr. Matt Knudson

Oregon State University

Agreement Number: DE-FE0000857

NETL Project Manager: Sara Zenner

A Little Knowledge is a Dangerous Thing?



Outline

- Motivation

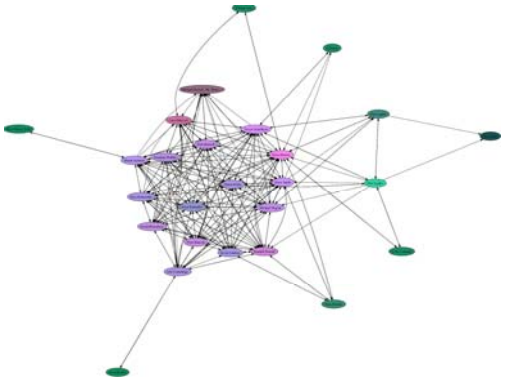
- Project Technology
  - Objective functions and self-organization
  - System properties

- Project Objectives
  - Sensor effectiveness
  - Self-organization and system reconfigurability

- Tasks/Milestones/Budgets

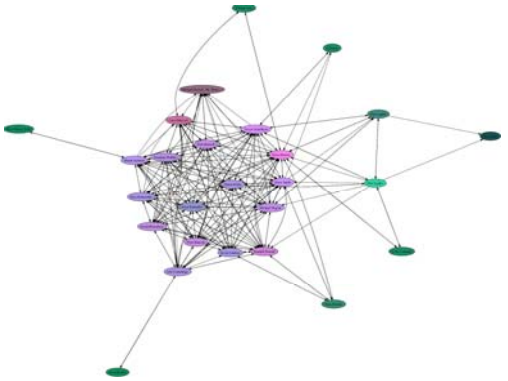
Motivation

- Where are we?
  - Advanced energy systems are becoming more interconnected
    - Larger, more distributed, more stochastic
  - Computation pushed further down the pipe
    - more powerful, cheaper, smaller devices



Motivation

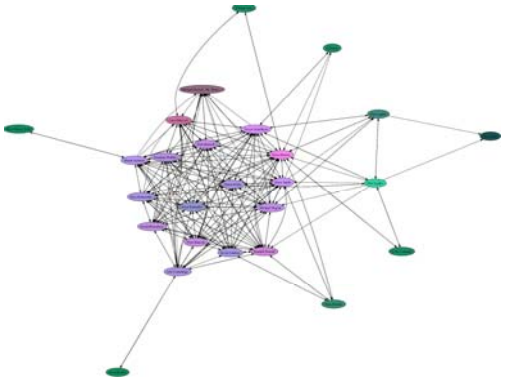
- Where are we?
  - Advanced energy systems are becoming more interconnected
    - Larger, more distributed, more stochastic
  - Computation pushed further down the pipe
    - more powerful, cheaper, smaller devices



- Where are we going?
  - Hybrid sensors
    - Electrical/bio/mechanical devices
  - Smart sensors
    - Tens of thousands of tiny, simple, unreliable sensors

Motivation

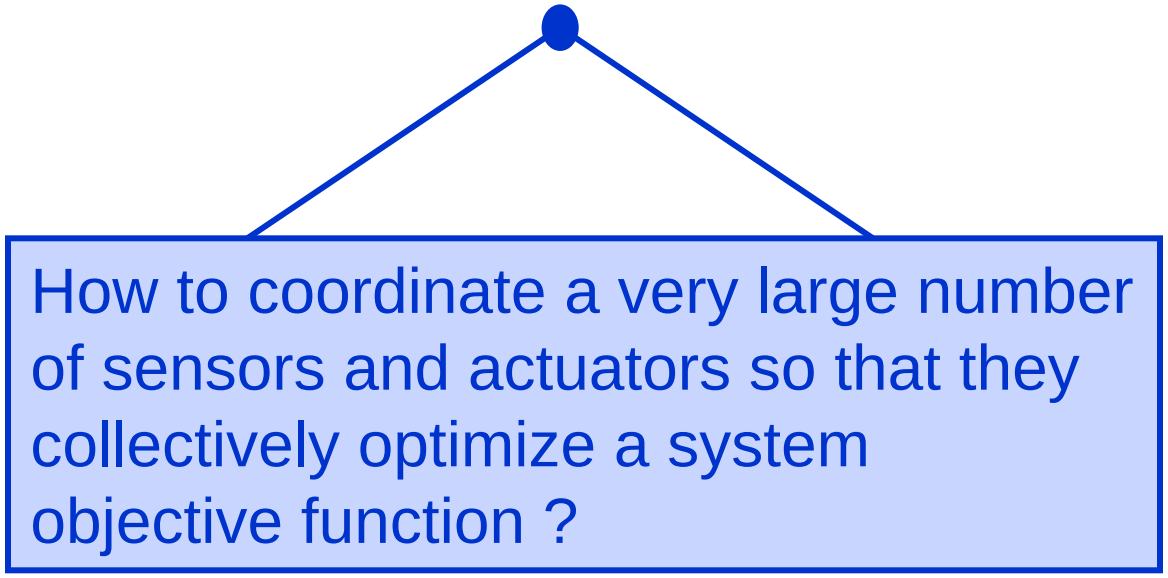
- Where are we?
  - Advanced energy systems are becoming more interconnected
    - Larger, more distributed, more stochastic
  - Computation pushed further down the pipe
    - more powerful, cheaper, smaller devices



- Where are we going?
  - Hybrid sensors
    - Electrical/bio/mechanical devices
  - Smart sensors
    - Tens of thousands of tiny, simple, unreliable sensors

- What do we need to account for:
  - Tens of thousands of sensors
  - Failing sensors
  - Dynamic and stochastic environments

Key Challenge



Where Should Focus Be ?

- *New optimization algorithms ?*
- *New control algorithms ?*

Where Should Focus Be ?

- *New optimization algorithms ?*

  No

- *New control algorithms ?*

  No

Where Should Focus Be ?

- *New optimization algorithms ?*

  No

- *New control algorithms ?*

  No

- *Focus on*
  - *What to control ?*
  - *What to optimize ?*
  - *What are "good system" properties ?*

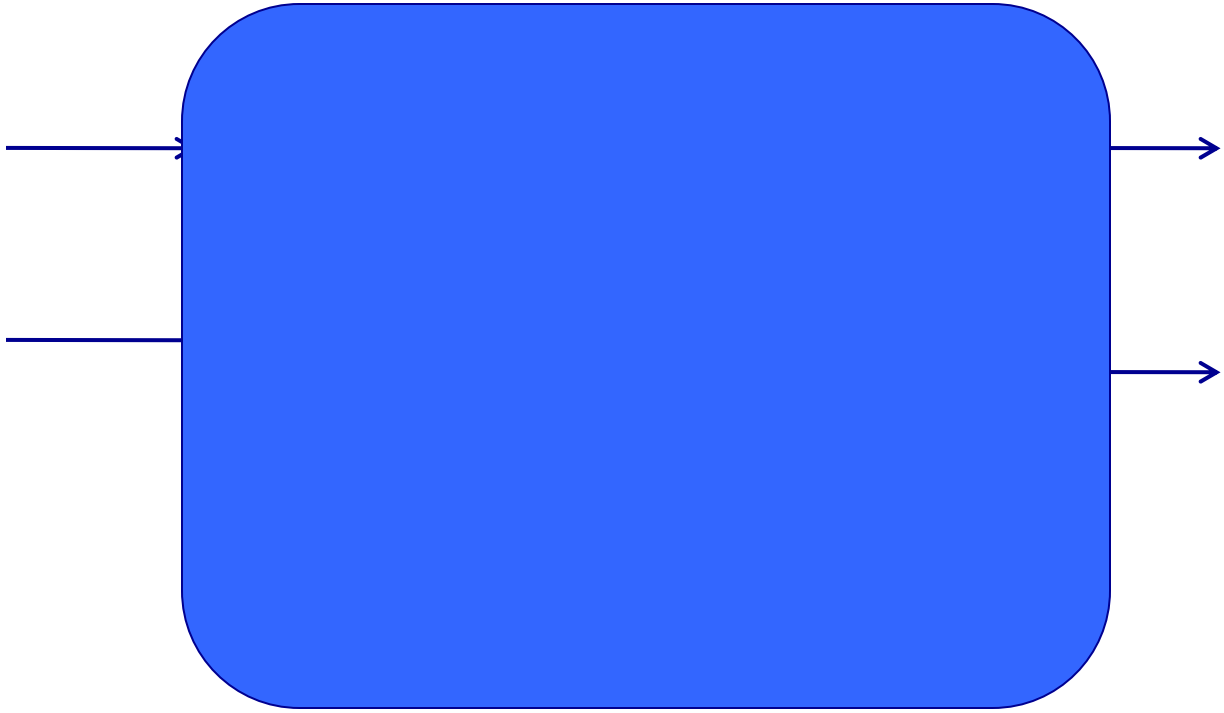
Cooperative Multiagent Systems

- System Description
  - Each sensor/sensor team has an *agent objective*
  - A *system objective* function rates the system's performance
- Important issues:
  - *How to set agent objective functions?*
  - *How to update them?*
  - *Can agents compute those objective functions?*
  - *What happens when information is missing?*
  - *What happens when some agents start to fail?*
  - *What happens when high level goals change?*

Outline

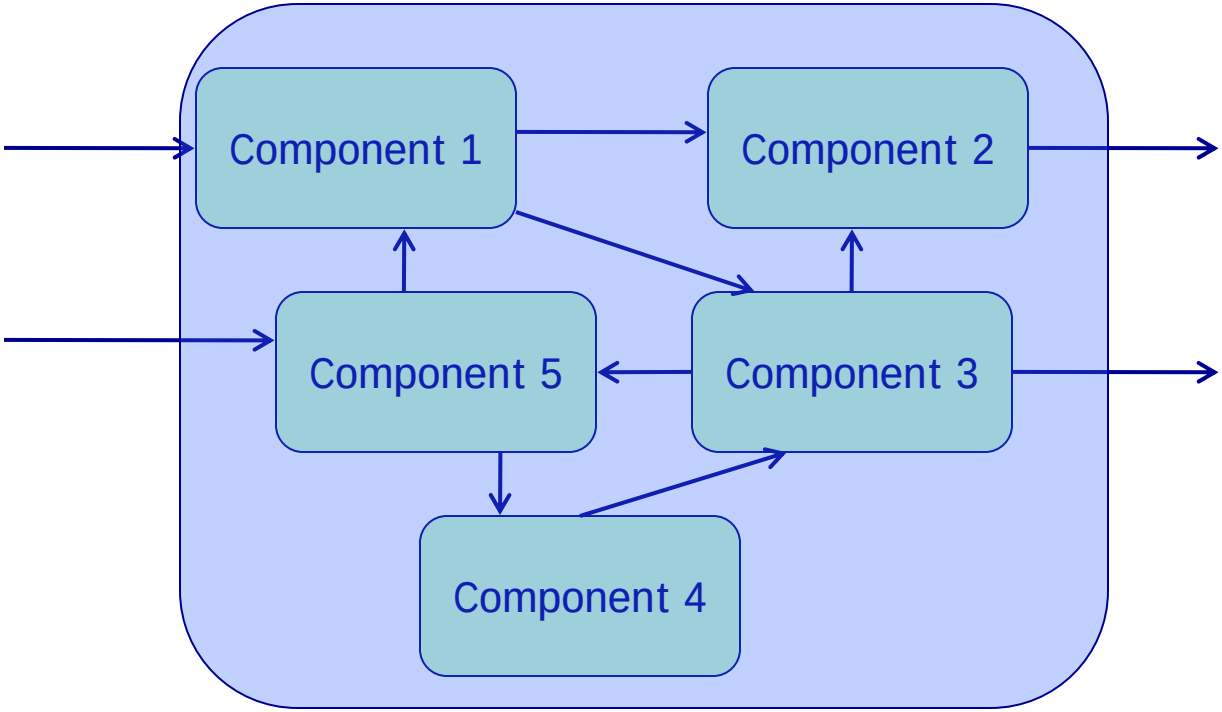
- Motivation
- Project Technology
  - Objective functions and self-organization
  - System properties
- Project Objectives
  - Sensor effectiveness
  - Self-organization and system reconfigurability
- Tasks/Milestones/Budgets

Objectives in Self-Organizing Systems



G(z): system objective

Objectives in Self-Organizing Systems



G(z): system objective

$g_1(z)$: comp 1 objective

$g_2(z)$: comp 2 objective

$g_3(z)$: comp 3 objective

$g_4(z)$: comp 4 objective

$g_5(z)$: comp 5 objective

Problem: In general, optimizing each g(z) will NOT optimize G(z)

Objectives in Self-Organizing Systems

$$G(z_1, z_2, z_3, z_4, z_5, z_6, z_7, z_8, z_9, z_{10}, z_{11}, z_{12})$$

comp 1 | comp 2 | comp 3 | comp 4 | comp 5

Objectives in Self-Organizing Systems

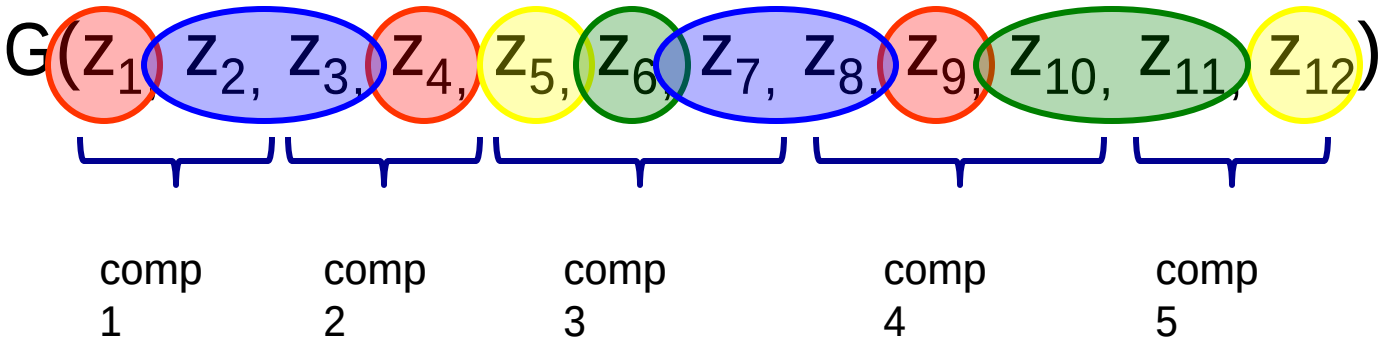
$$G(z_1, z_2, z_3, z_4, z_5, z_6, z_7, z_8, z_9, z_{10}, z_{11}, z_{12})$$

comp 1	comp 2	comp 3	comp 4	comp 5

- Two solutions to component/system objective mismatch

  1. Get better objective functions for each subsystem

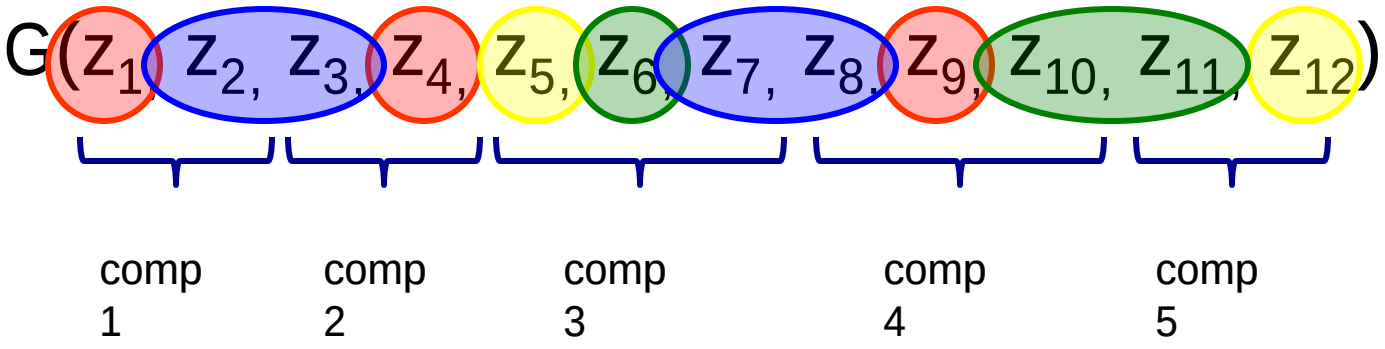
Objectives in Self-Organizing Systems



- Two solutions to component/system objective mismatch

  1. Get better objective functions for each subsystem

Objectives in Self-Organizing Systems



- Two solutions to component/system objective mismatch

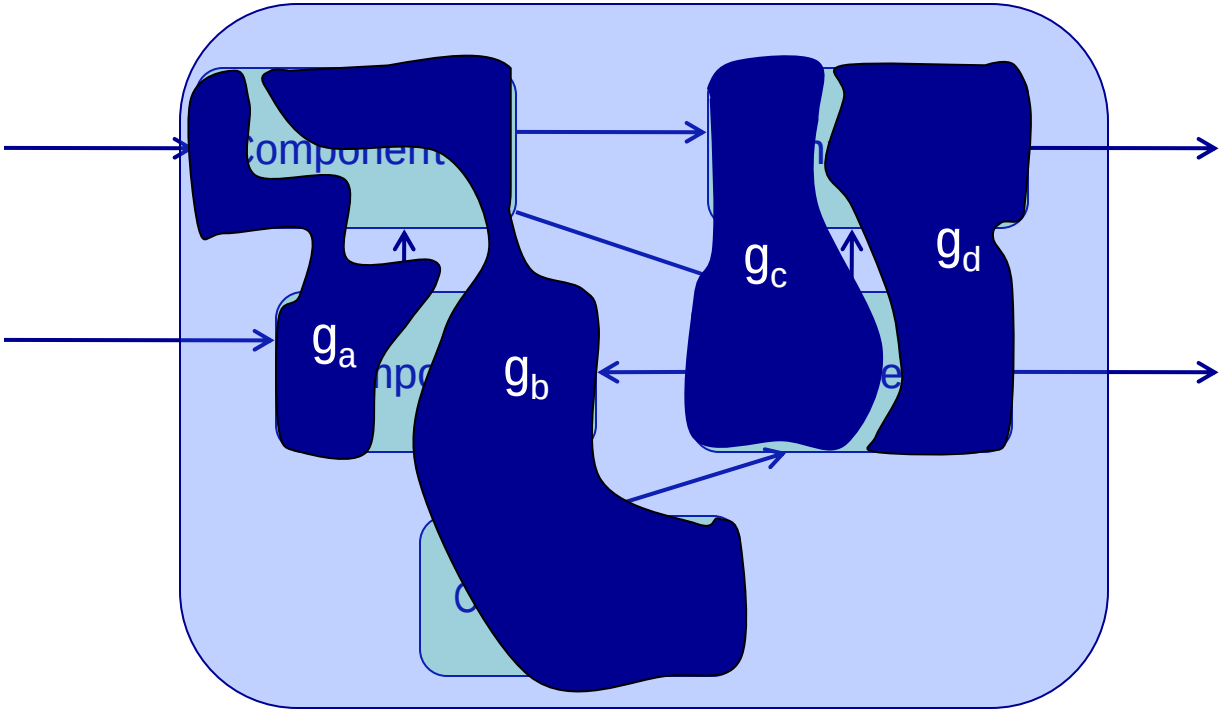
1. Get better objective functions for each subsystem

2. Get better system decomposition

   Variable set *a*: z_1, z_4, z_9

   - Variable set *b*: z_2, z_3, z_7, z_8
   - Variable set *c*: z_5, z_{12}
   - Variable set *d*: z_6, z_{10}, z_{11}

Objectives in Self-Organizing Systems



Problem: Variable sets may have no "intuitive" objective function. What is a combination of subsystems trying to achieve?

$g_a(z)$: Varset *a* objective

$g_b(z)$: Varset *b* objective

$g_c(z)$: Varset *c* objective

$g_d(z)$: Varset *d* objective

Desirable System Properties

- Factoredness:
  - Alignment
  - Modularization
  - Self-organization

$$\mathcal{F}_{g_i} = \frac{\sum_{z'} u[((g_i(z) - g_i(z'))(G(z) - G(z'))]}{\sum_{z'} 1}$$

$$(z'_{-i} = z_{-i})$$

Is what's good for me good for the full system ?

- Sensitivity
  - Signal to noise
  - Locality

$$L(g_i, z, z') = \frac{\|g_i(z) - g_i(z - z_i + z'_i)\|}{\|g_i(z) - g_i(z' - z'_i + z_i)\|}$$

$$L(g_i, z) = \frac{\sum_{z'} L(g_i, z, z')}{\sum_{z'} 1}$$

Can I extract what's good for me from signal ?

General Solution

- To get agent objective with high factoredness and sensitivity, start with:

$$g_i(z) = G(z) - G(z_{-i} + c_i)$$

→ g_i is aligned with G
  $G(z_{-i}+c_i)$ is independent of i
g_i has cleaner signal than G
  $G(z_{-i}+c_i)$ removes noise

- If g, G differentiable, then:

$$\frac{\partial G(z_{-i} + c_i)}{\partial z_i} = 0$$

$$\frac{\partial g_i(z)}{\partial z_i} = \frac{\partial G(z)}{\partial z_i}$$

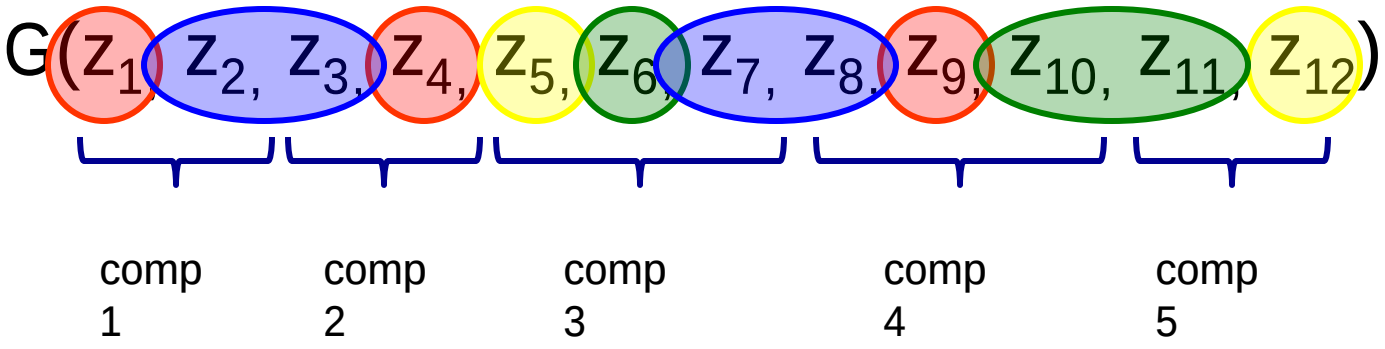
Outline

- Motivation
- Project Technology
  - Objective functions and self-organization
  - System properties
- Project Objectives
  - Sensor effectiveness
  - Self-organization and system reconfigurability
- Tasks/Milestones/Budgets

Project Objectives

1. Derive criteria for assessing sensor effectiveness and system impact
   - Quantify sensor configuration effectiveness
   - Allow trade-offs in communication, computation and sensing requirements
   - Develop new objective functions for sensors/sensor sets
2. Demonstrate effectiveness and reconfigurability of sensors to changing performance criteria
   - Response to changes in systems
   - Response to sensor failures
   - Response to changing system level criteria

Back to Self-Organizing Systems



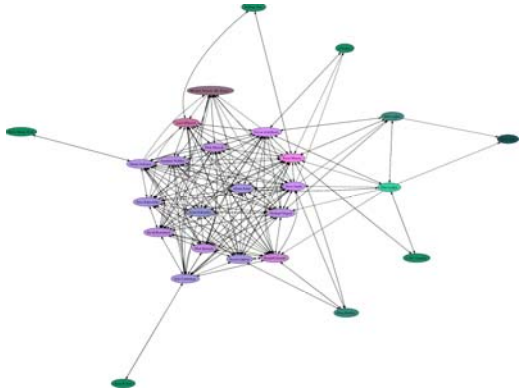
- Two solutions to component/system objective mismatch
  - Get better objective functions for each subsystem
  - Get better system decomposition
    - Variable set *a*: z_1, z_4, z_9
    - Variable set *b*: z_2, z_3, z_7, z_8
    - Variable set *c*: z_5, z_{12}
    - Variable set *d*: z_6, z_{10}, z_{11}

- Factoredness ?
- Sensitivity ?

Difference objectives ?

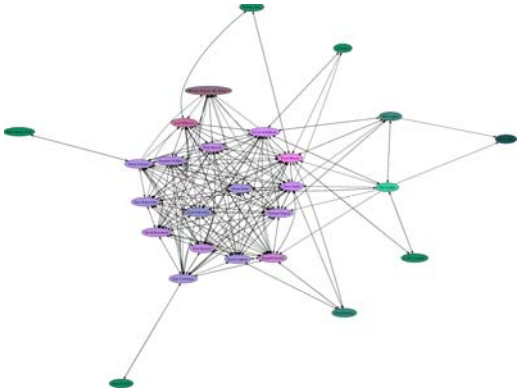
Expected Benefits

- Directly to advanced energy systems
  - More efficient information collection
  - Quick response to sudden developments
  - Autonomous system reconfiguration

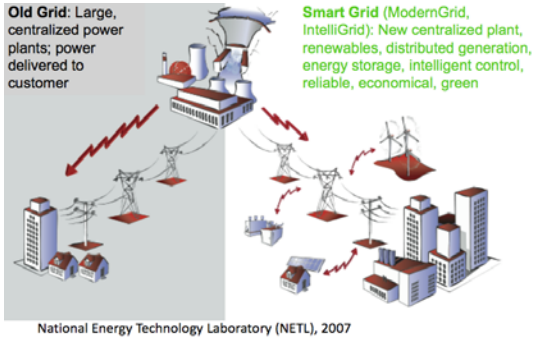


Expected Benefits

- Directly to advanced energy systems
  - More efficient information collection
  - Quick response to sudden developments
  - Autonomous system reconfiguration



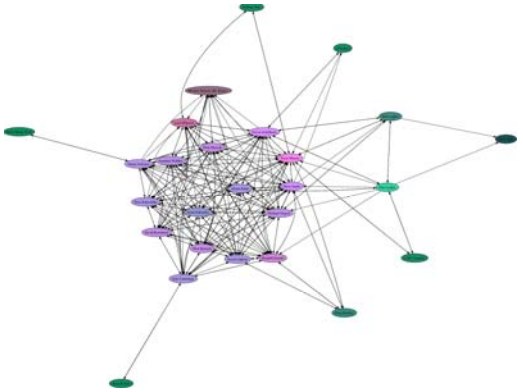
- To the Department of Energy and US Govt
  - Smart power grid
  - Coordinated search and rescue
  - Self-organizing nano/micro devices



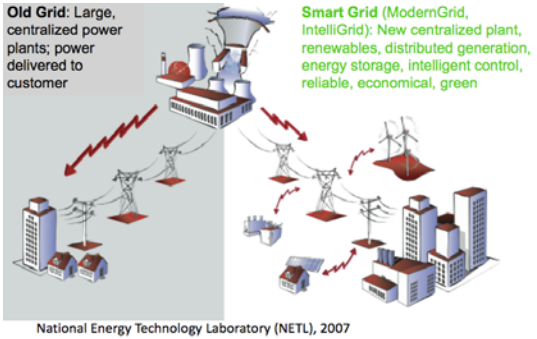
National Energy Technology Laboratory (NETL), 2007

Expected Benefits

- Directly to advanced energy systems
  - More efficient information collection
  - Quick response to sudden developments
  - Autonomous system reconfiguration

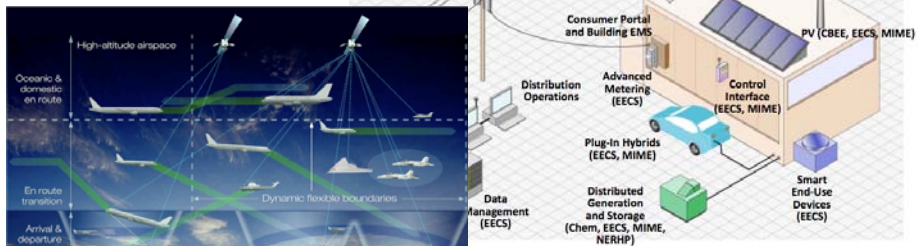


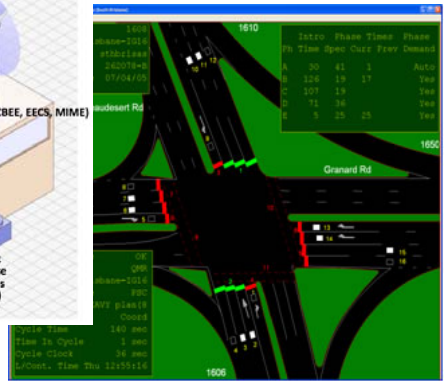
- To the Department of Energy and US Govt
  - Smart power grid
  - Coordinated search and rescue
  - Self-organizing nano/micro devices



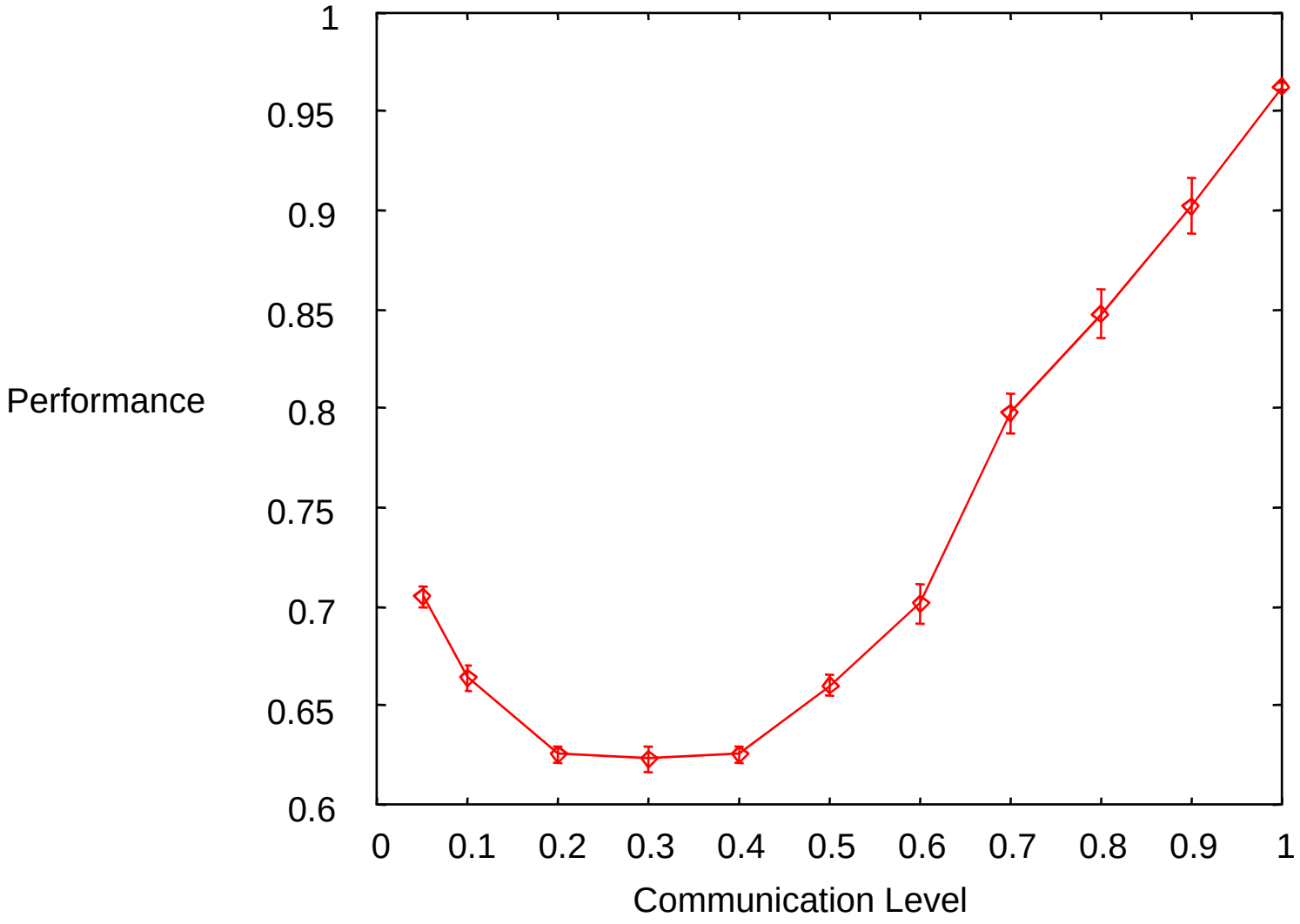
National Energy Technology Laboratory (NETL), 2007

- To American Public
  - Smart house
  - Smart highways
  - Smart airports

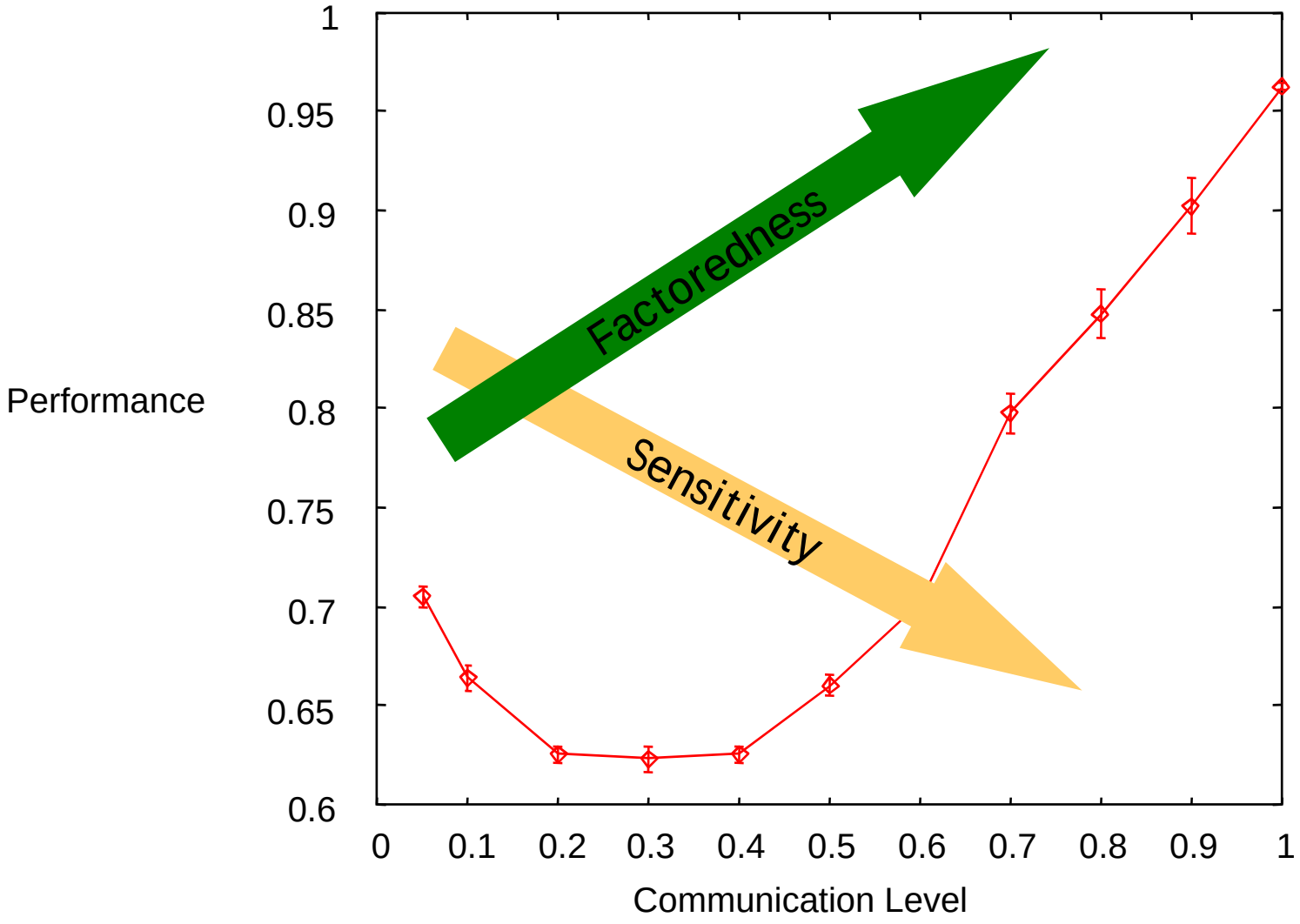




So, what is the impact of “a little knowledge”?



So, what is the impact of “a little knowledge”?



Outline

- Motivation
- Project Technology
  - Objective functions and self-organization
  - System properties
- Project Objectives
  - Multiagent Sensor effectiveness
  - Self-organization and system reconfigurability
- Tasks/Milestones/Budgets

Dates and Dollars for Each Budget Period

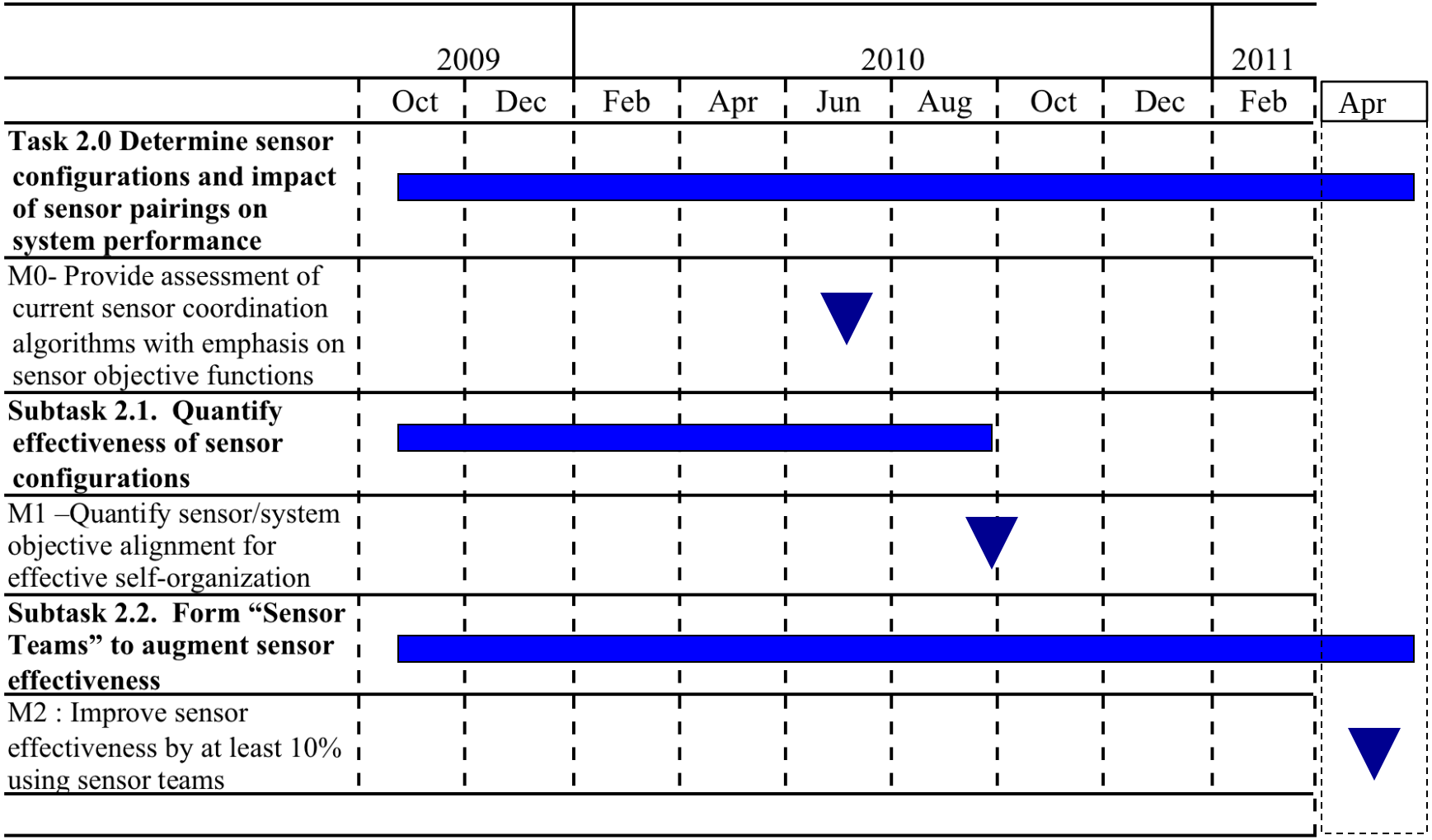
	Budget Period 1 (16 months)		Budget Period 2 (20 months)		Total	
Federal	$272,000	78.4%	$436,206	80.9%	$708,206	79.9%
Cost Share*	$75,096	21.6%	$103,292	19.1%	$178,388	20.1%
Total	$347,096	100%	$539,499	100%	$866,595	100%

***** Oregon State University

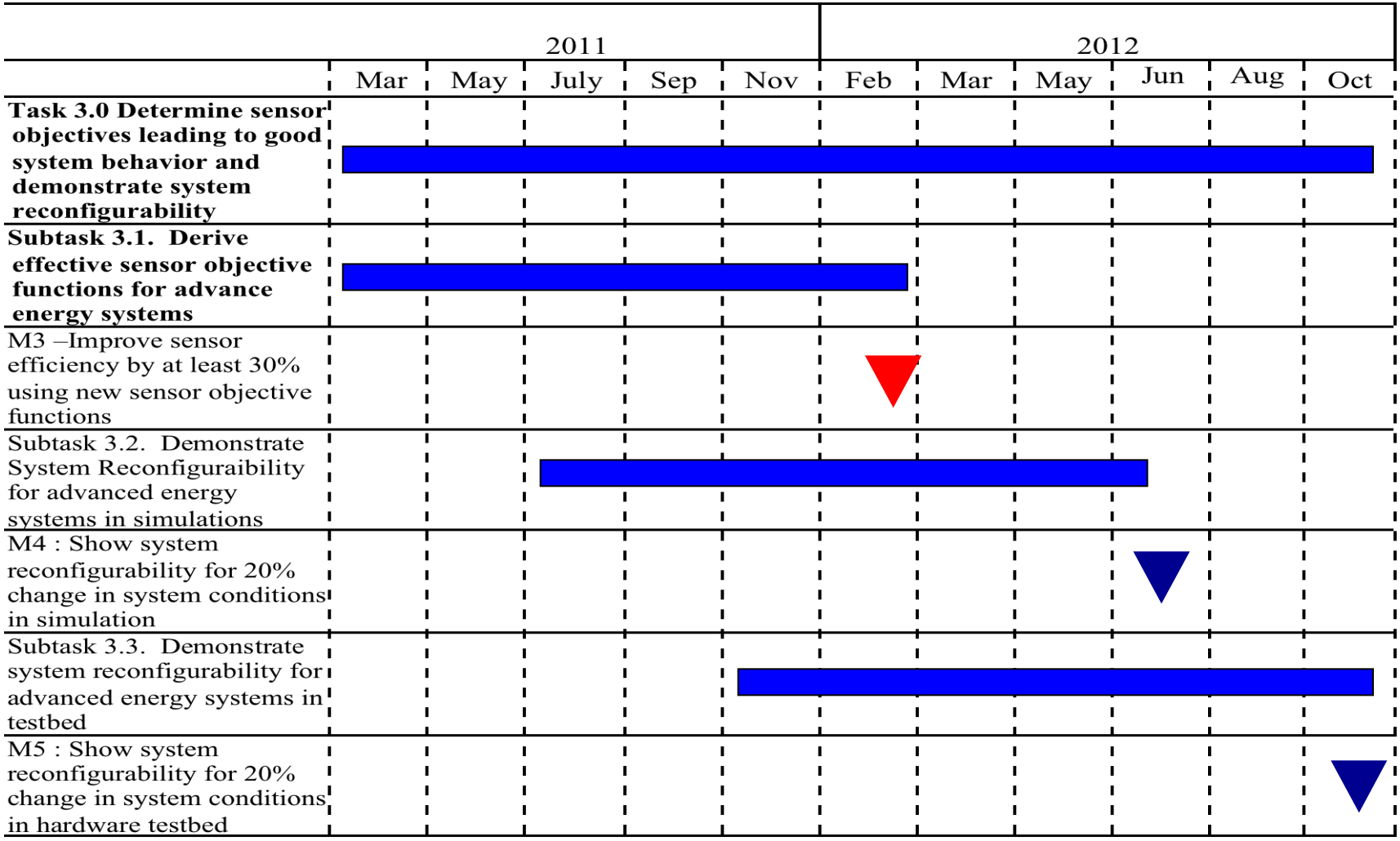
Tasks

Task	Subtask	Task
1.0		Project management and planning
2.0		Determine sensor configurations and impact of sensor pairings on system performance
	2.1	Quantify effectiveness of sensor configurations
	2.2	Form sensor teams to augment sensor effectiveness
3.0		Determine sensor objectives that lead to good system behavior and demonstrate system reconfigurability
	3.1	Derive effective sensor objective functions for advanced energy systems
	3.2	Demonstrate system reconfigurability for advanced energy systems in simulation
	3.3	Demonstrate system reconfigurability for advanced energy systems in harware testbed

Budget Period 1



Budget Period 2



▼ : Go - no go decision point

Questions?

?

Contact info:
Kagan Tumer
Oregon State University

kagan.tumer@oregonstate.edu
http://engr.oregonstate.edu/~ktumer