BMD Agents: An Agent-Based Framework to Model Ballistic Missile Defense Strategies

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- The views and conclusions contained in this presentation are those of the author and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the U.S. Government.

Acknowledgements

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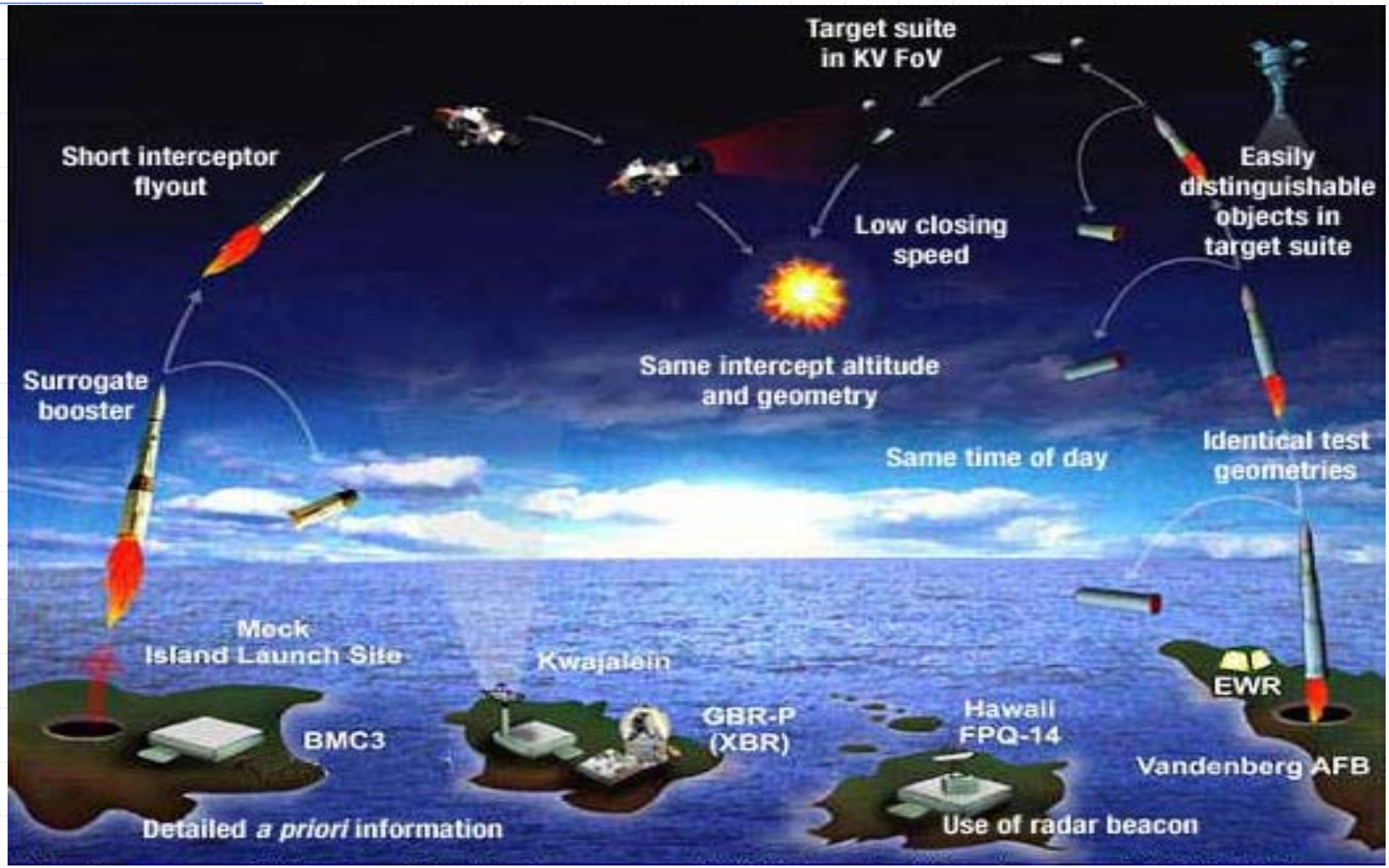
The environment



http://www.ucsusa.org/global_security/bmd/bmd_test.html

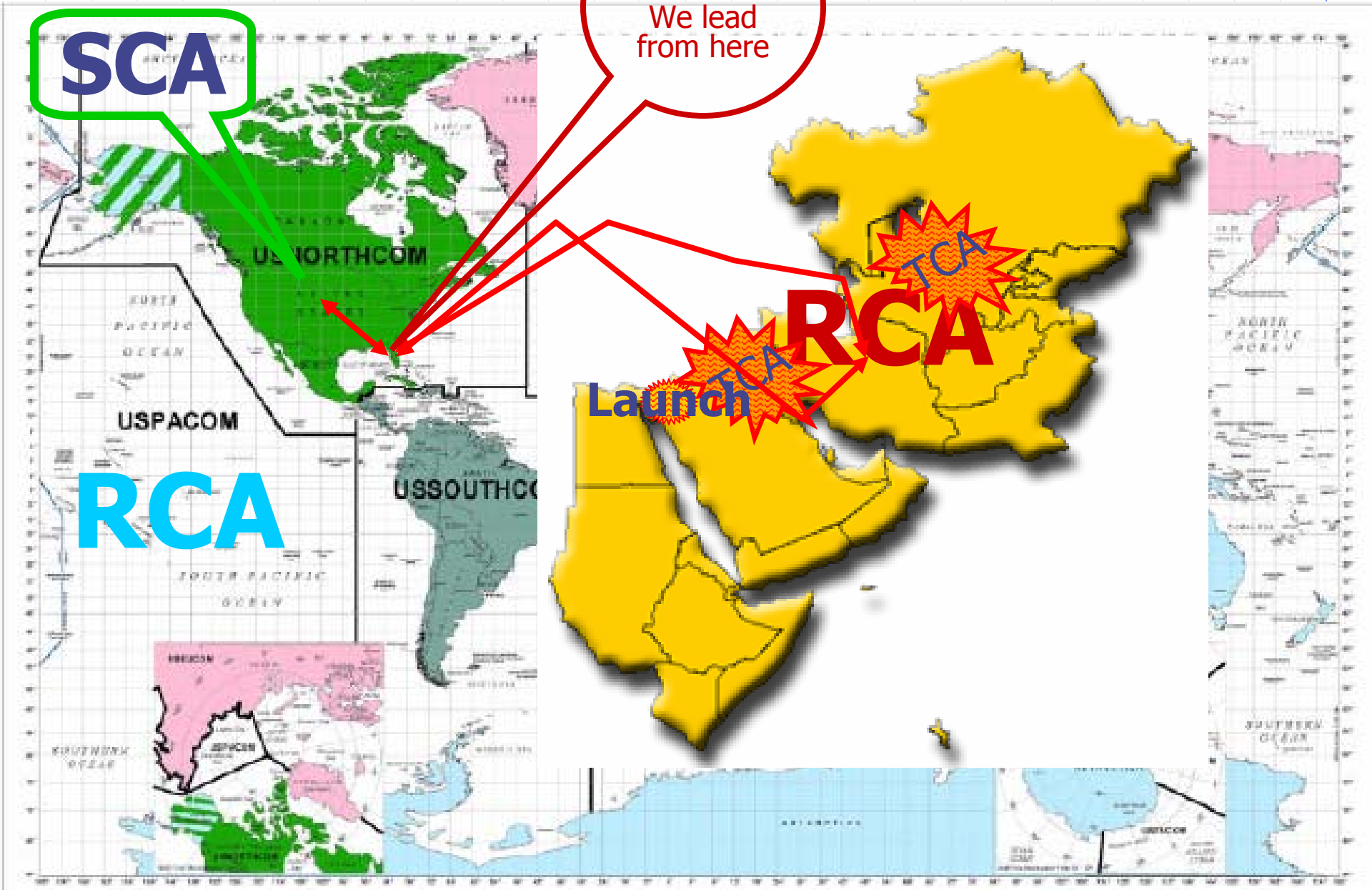
BMD modeling requirements

- Must account for
  - Deliberate planning
  - Crisis action planning
- Individuals follow a *kill chain*
  - Map the individual duties to agents
- Optimize QoS Measures
  - MoP: Measure of Performance
  - MoE: Measure of Effectiveness

Modeling choice

- Use a collection of agents based on the roles they play in the missile defense environment
  - Strategic Command Agents
    - Directs high-level strategies among many regions
  - Regional Command Agents
    - Coordinates regions consisting of multiple theaters
  - Theater Command Agents
    - Directs theater-level actions

In pictures

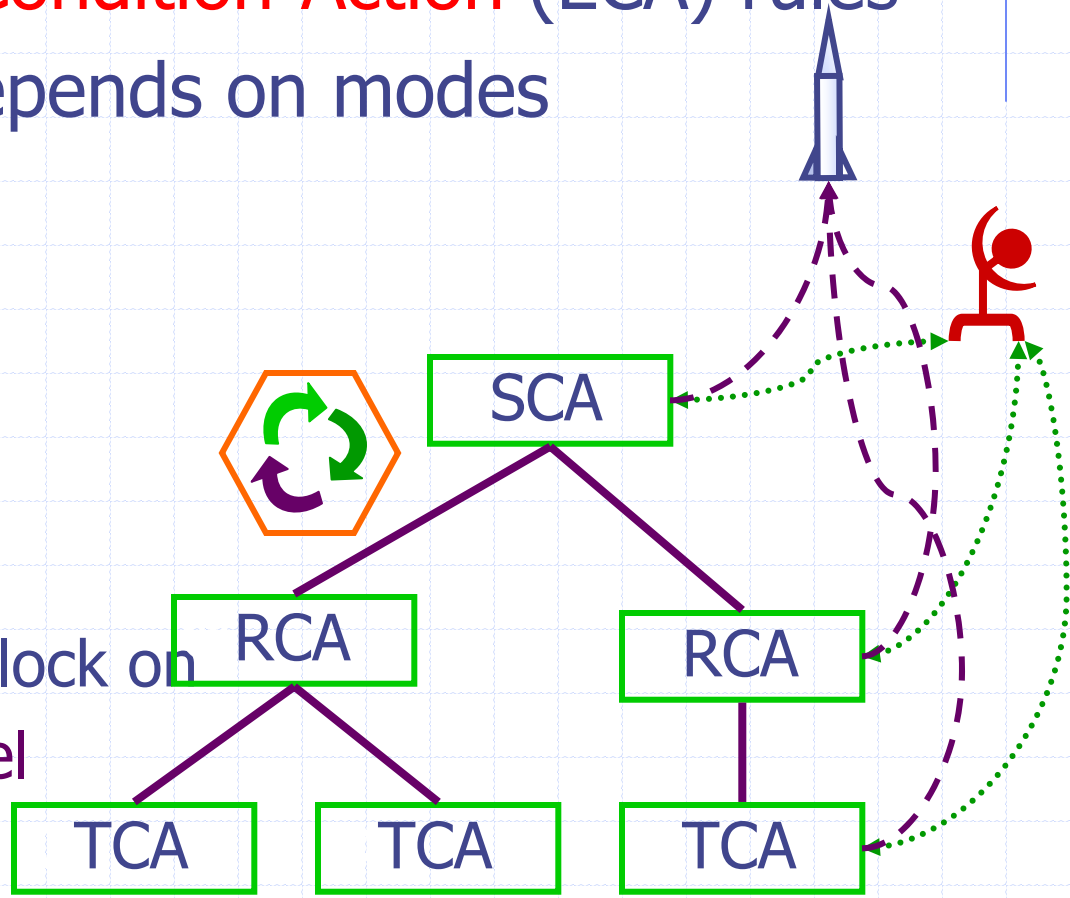

SCA
SCA
We lead
from here
USNORTHCOM
USPACOM
USSOUTHCO
RCA
TCA
RCA
TCA
Launch

The operating environment

- SensorNet
  - Information gathered (using sensors) about flying objects of interests are broadcasted here
- WeaponsNet
  - Operational status about weapons systems are broadcasted here

Modeling details

- Build using Event-Condition-Action (ECA) rules
- Agents behavior depends on modes
  - Peacetime
  - Pre-hostilities
  - Hostilities
  - Post hostilities
- Duty cycle
  - Acquire target and lock on
  - Launch, wait, cancel
  - Assess



Designing agents 1: SCAs

- Obtain information from
  - SensorNet, WeaponsNet, AND *friends,* and
- Assigns tasks with timing constraints to subordinates consisting of
  - Changing modes (peace, war, pre-war, post-war)
  - Computing regional objectives of tracking, and destroying flying objects
  - Altering and/or canceling current objectives
- Informs *friends* as necessary

Designing agents 2: RCAs

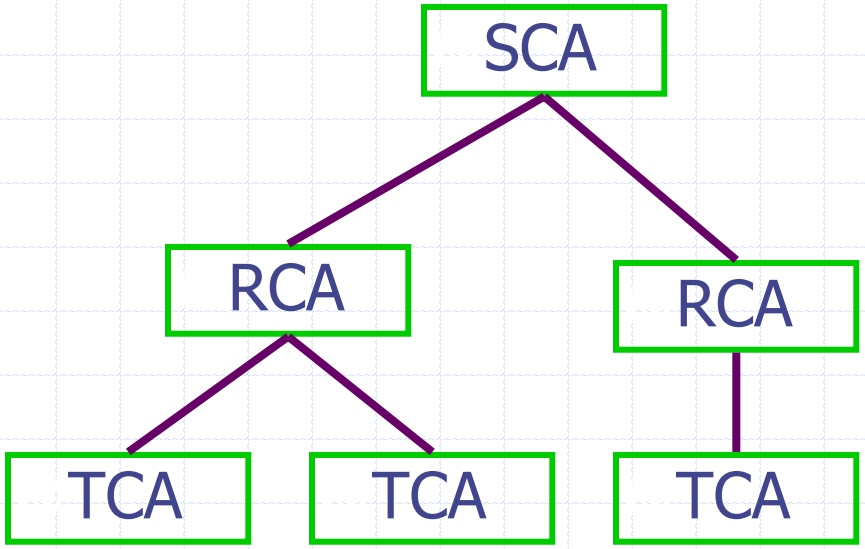
- On receiving directives from superiors
  - Get data from SensorNet, WeaponsNet and
- Assign time-constrained tasks to TCAs consisting of
  - Pass on changing mode commands (war, pre-war, post-war) to subordinates, and change own mode.
  - Computing regional firing, holding (fire) and canceling fire orders and assign them to TCAs
- Send feedback acknowledgements (about their ability to comply with orders) to superiors

Designing agents 3: TCAs

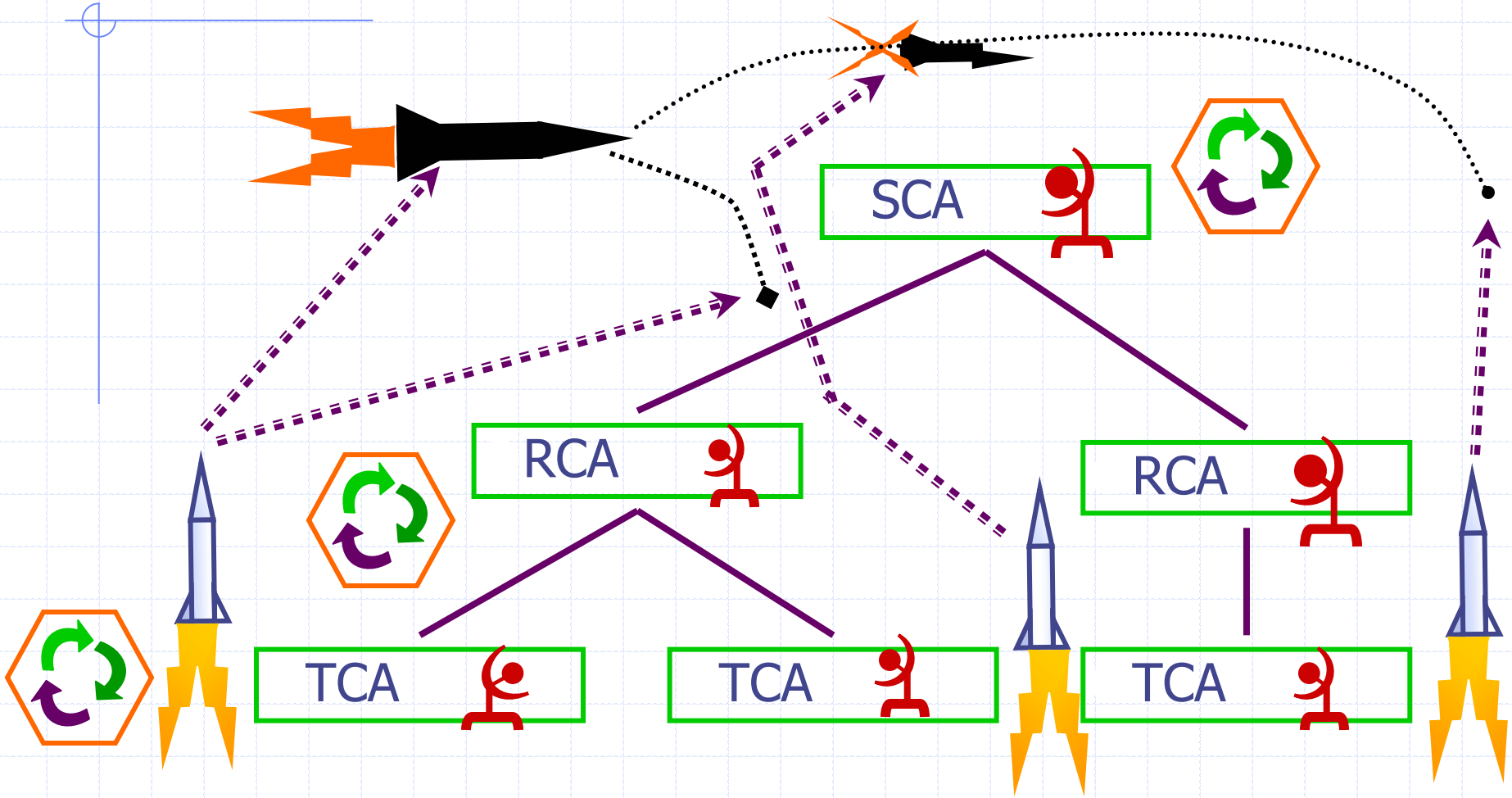
- On receiving directives from superiors
  - Get data from SensorNet, WeaponsNet and
  - Change mode on command (war, pre-war, post-war)
  - Execute the duty cycle of acquiring/locking on/firing/ assessing damage to the target
  - On command, recompute firing/reload/holdfire/cancel schedules per weapon under own command
- Send feedback acknowledgements (about their ability to comply with orders) to superiors
- Inform sensorNet an weaponsNet about changes to tracked targets and weapons status

Designing agent communities

- Need to design command, control and communication (C^3I) structure for agents to model BMD functionality
- Use real-life examples

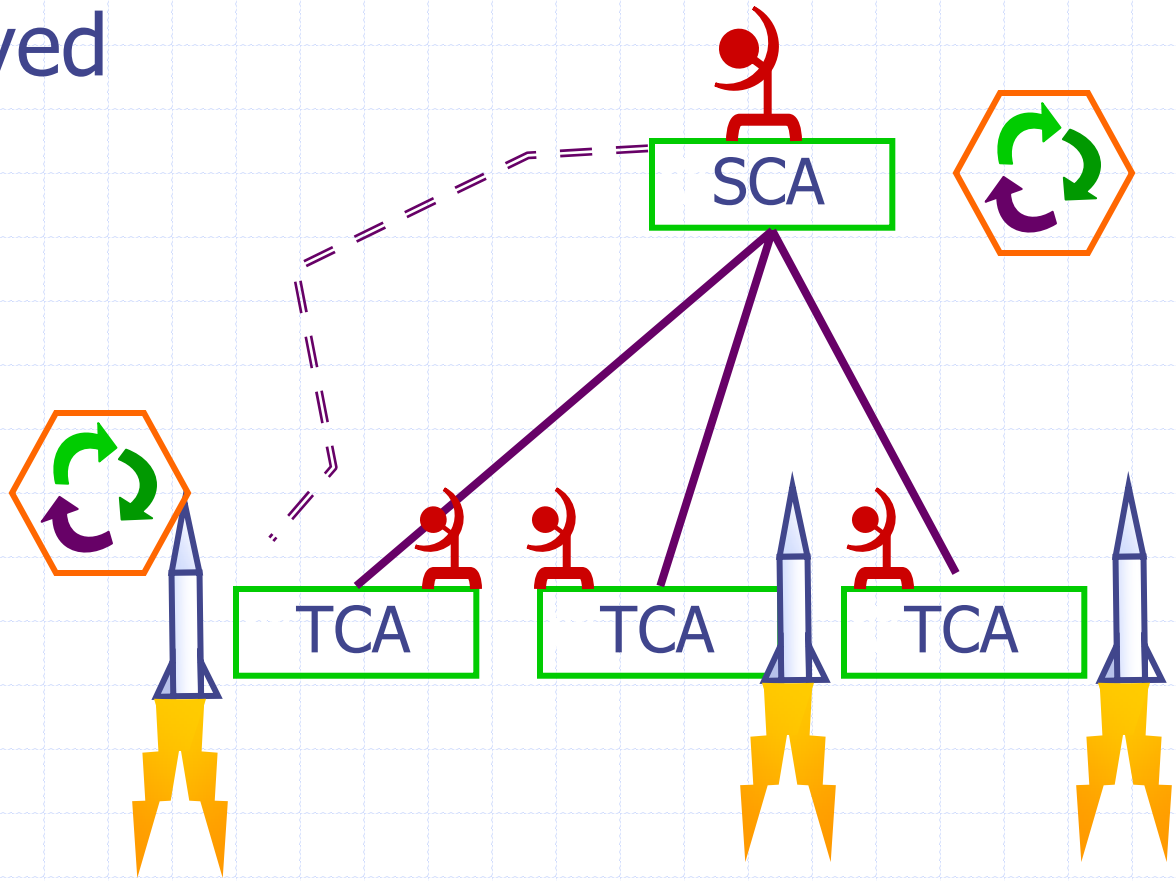


Command structure 1: Hierarchical



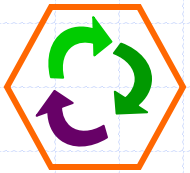
Command structure 2: Partially flattened

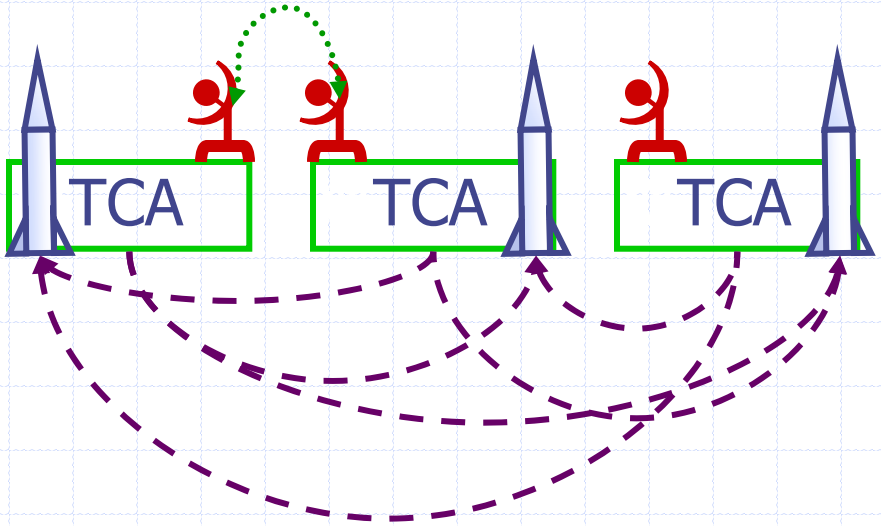
- RCAs removed



Command structure 3: Flattened

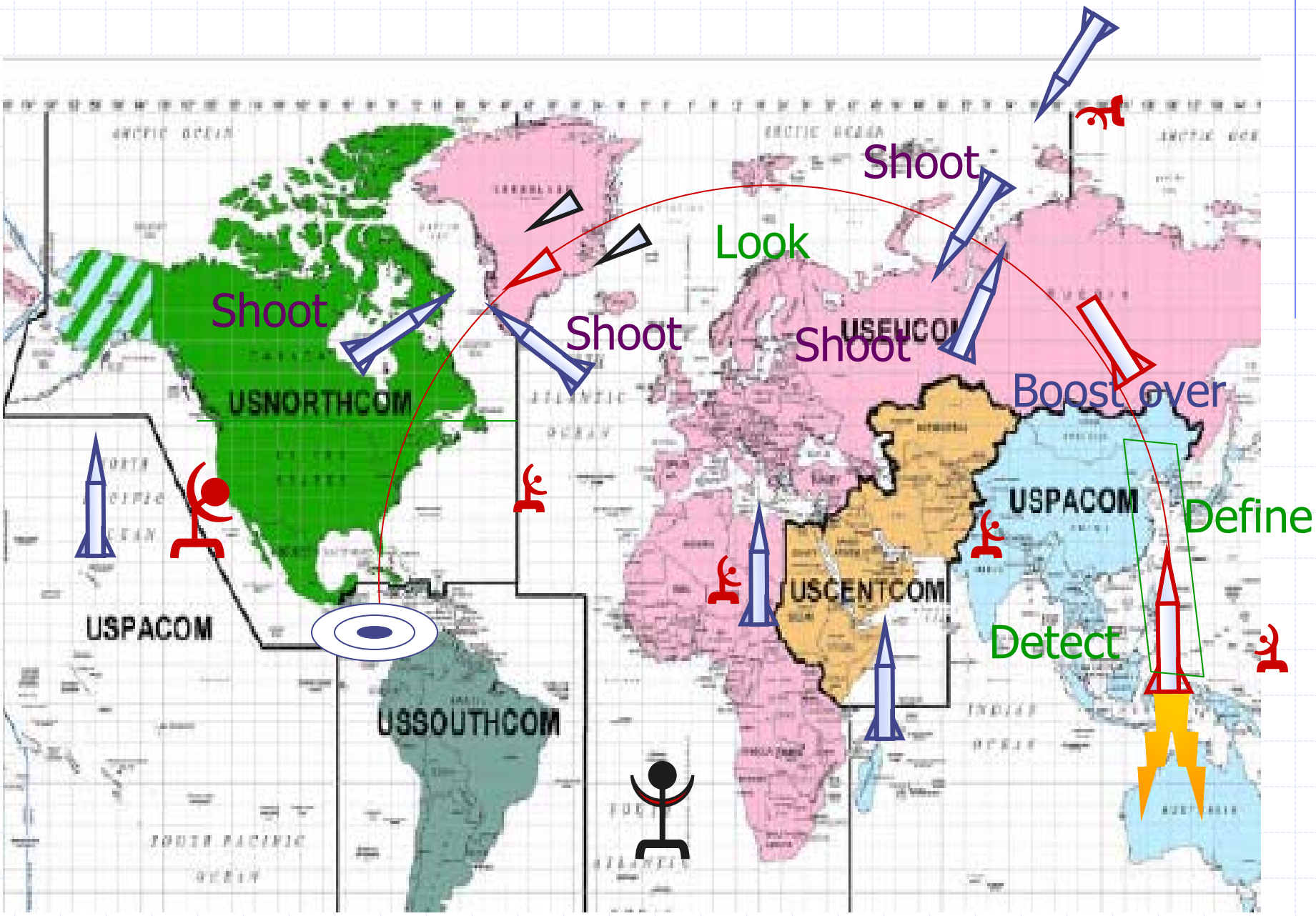
- TCAs work autonomously





Composing agents: C^2 structures

- A tree consisting of at most 3 levels
- Every level has at most *one type* of agents
- Agents listed in the SCA/RCA/TCA order
- Every agent knows its superiors/subordinates
- Every SCA knows all of its *friends*
- Lemma: A simple static analysis algorithm can detect if any collection of agents is a C2 structure
- Limitation: Does not account for duty polymorphism (i.e. SCA's doing RCA's work)


Shoot
Look
Shoot
Shoot
Shoot
Boost over
Define
Detect
USNORTHCOM
USPACOM
USSOUTHCOM
USCENTCOM
USPACOM

Analysis objectives

- Can the treat missiles be destroyed before it hits or scatters debris over intended target?
  - Missiles entering airspace need to be identified and categorized as threat, potential threat, or benign
  - Targets and travel trajectories/times be computed and all fragments tracked and destroyed in threat missiles
  - Commanders need to obtain authority to aim at missiles
    - This authority need to propagate through the command chain
    - Takes time to lock on and fire
    - Do follow-up shots destroy the threat missile?
    - If object is reclassified as benign, need to cancel/delay firing

Preliminary results

- Compute periods for duty cycles of agents using
  - Worst-case estimates for command execution times
  - Performance delays of weapon systems
- Compute command propagation times through statically-composed C2 structures using
  - Worse-case communication delays
  - Computed duty cycle periods
- Using these estimates, one can compute if a properly identified threat missile can be intercepted with a particular weapon

Limitations

- Need to account for
  - Hit/destroy probabilities
  - Reclassification of missile status and the ability to recall/re-target missiles
- Need to incorporate measures

Measures

- Measures of Effectiveness, such as
  - Can launches (or repeat launches) destroy threat missiles?
  - Does the system hold fire if missile status is reclassified?
- Measures of Performance, such as
  - How much above ground are they destroyed?
  - Delay in reacting to reclassification

Related work

- Many approaches
  - Force-structure-based
  - Strategy-based
- Some examples:
  - Athens: C2 Theory, *IEEE Trans. on Automatic Control* 32, 4 (1987), pp. 286-293
  - Michael, Pace, Shin, Tummala, Weller, Miklakski, Babbit: Test and evaluation of BMD systems, NPS TR-CS-03-007, 2003
  - Garwin: A hole in the missile shield, *Scientific American*, 2004, pp. 70-79

Summary

- Presented a preliminary ECA rule-based agent framework to capture BMD C2 requirements where
  - Strategy and policy are written as BMD rules
- A preliminary formulation of a well-formed agent society for BMD C2
- A back-of-the-envelope timing calculation

Ongoing work

- Experimenting with a model that uses probabilistic temporal reasoning
  - (Probabilistic Temporal Agents of Kraus et al.)
- Using rules to code policies and strategies
- Formulating a framework for both
  - Hierarchically building the MoEs and MoPs
  - Computing
    - Probability of achieving the numbers
    - Schedules for launches