

Finite State Machines for Creating, Evaluating, and Refining Air-to-Air Combat Tactics

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The logo for Applied Physics Laboratory (APL) consists of the letters 'APL' in a large, bold, sans-serif font.

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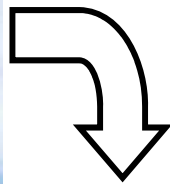
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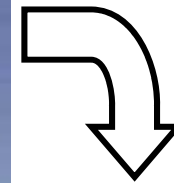
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Evolution of Unmanned Military Aviation

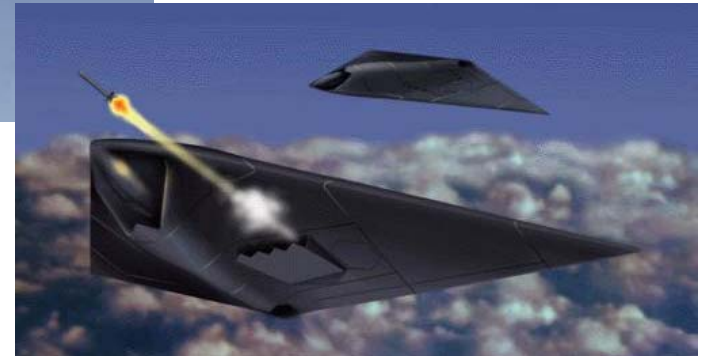
Reconnaissance



Air-to-Ground



Air-to-Air



Why Don't We Have Air Superiority UAVs Yet?

- **Still lots of low-hanging fruit in ISR / ground attack**
- **No sense of urgency**
 - Our manned fighters and pilots are head and shoulders above the competition
 - This will change as soon as an Iranian UCAV shoots down an F-16
- **Control logic is more difficult**
 - ISR: Fly from A to B; snap a picture
 - Air-to-Ground: Fly from A to B; drop a bomb
 - Air-to-Air: Umm... Well...

Who Will Teach the UAV Air-to-Air Tactics?

**Create
Building Blocks**



**Put the
Pieces Together**

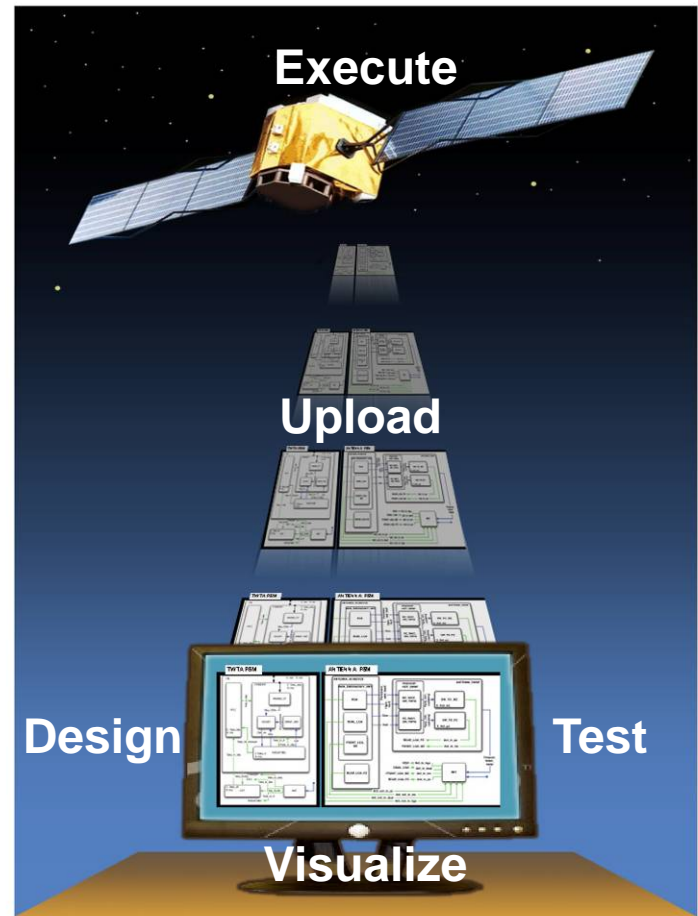


Vision for Autonomous Air Combat Tactics Design

- **Professional tactician designs tactics visually**
 - No programming experience necessary
 - Inputs and outputs in terms pilots understand
- **Evaluate tactics before use**
 - In simulation
 - Using mathematical proofs
- **Monitor performance during/after engagement**
 - Understand thoroughly the strengths and weaknesses
- **Refine tactics in the field**
 - After short engagements
 - During long engagements?

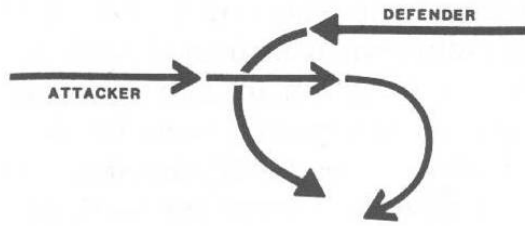
ExecSpec: State-Machine Autonomy System

- Developed for unmanned spacecraft
 - APL internal and NASA funding
- Visual, building-block design environment
- Automated verification
 - Prove that specification requirements are met
 - Provide counter-examples if not met
- Upload to spacecraft and execute
 - Input file only; *not* a new executable
- Real-time visual feedback

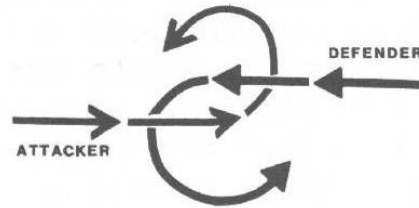


Representing Tactics as State Machines

Nose-to-Nose Turn



Nose-to-Tail Turn



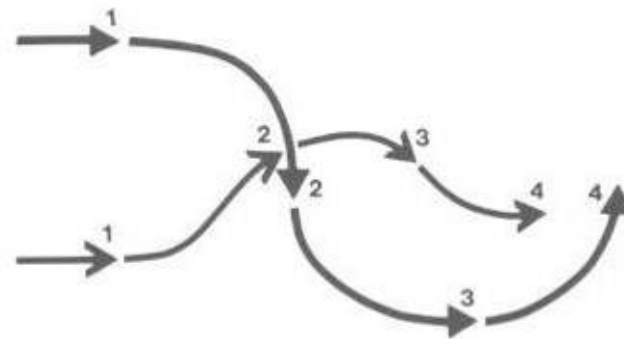
Primitive
Operations

+

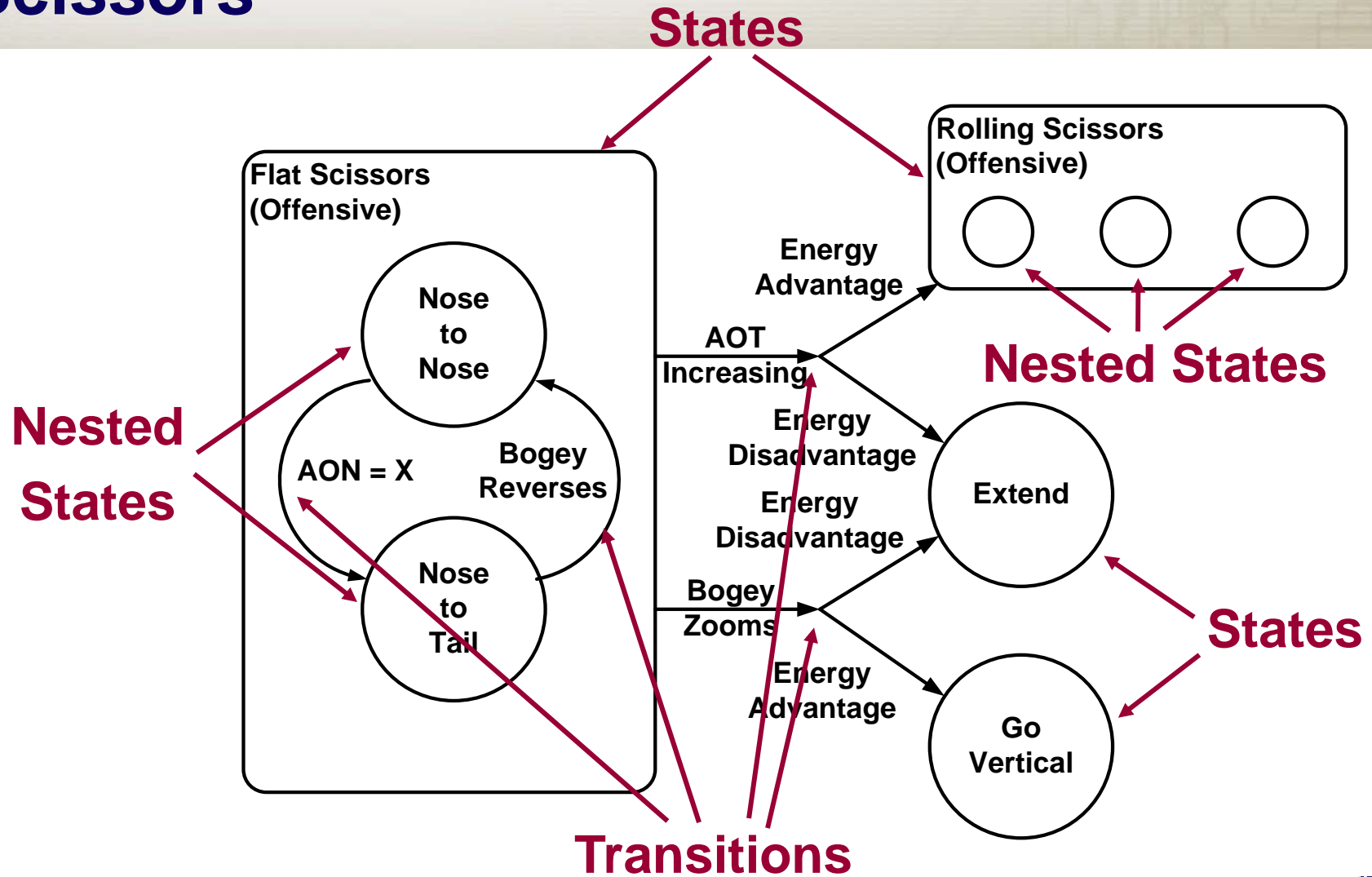
State machine times
the reversals and
determines
when/whether to
disengage

Flat Scissors

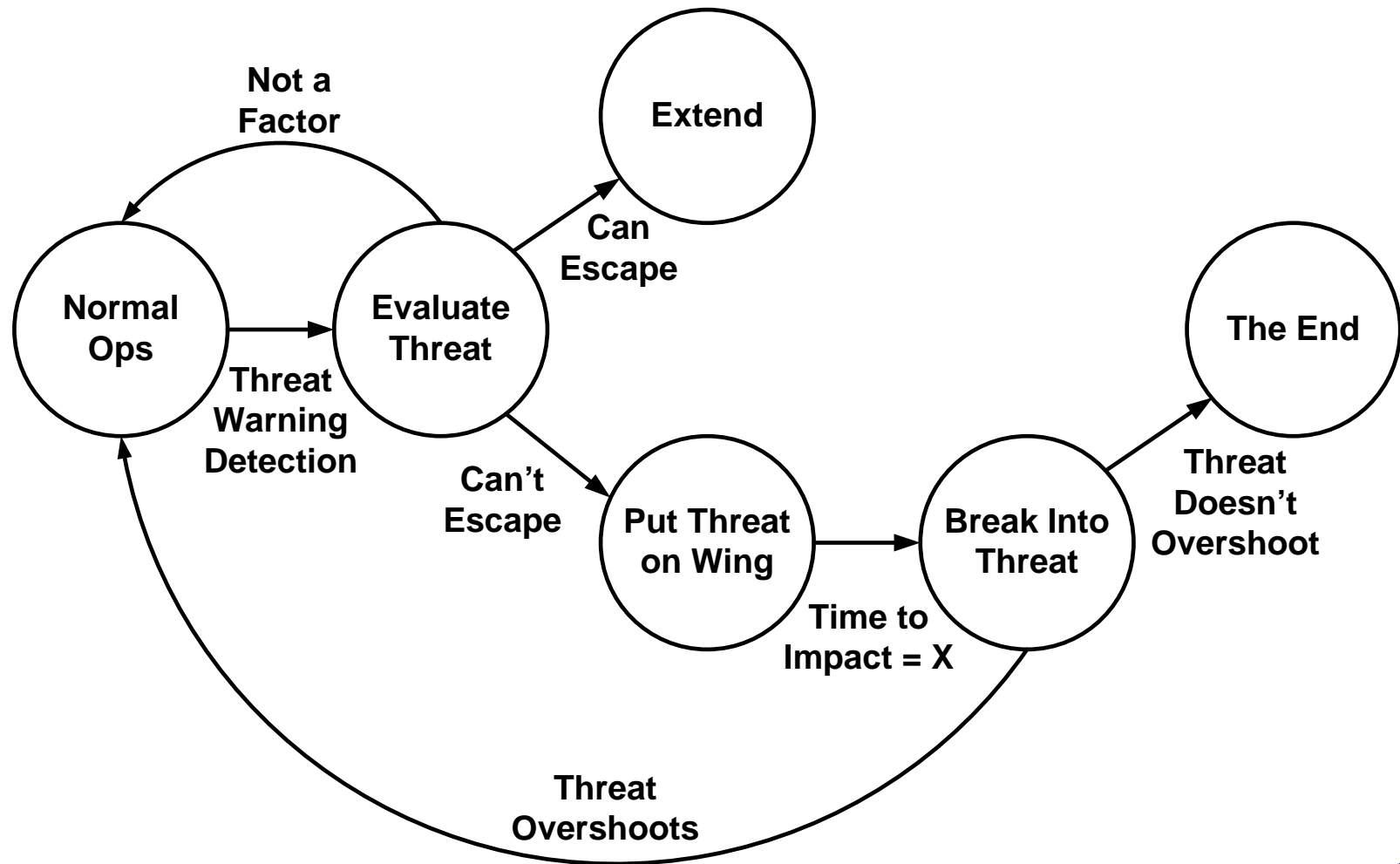
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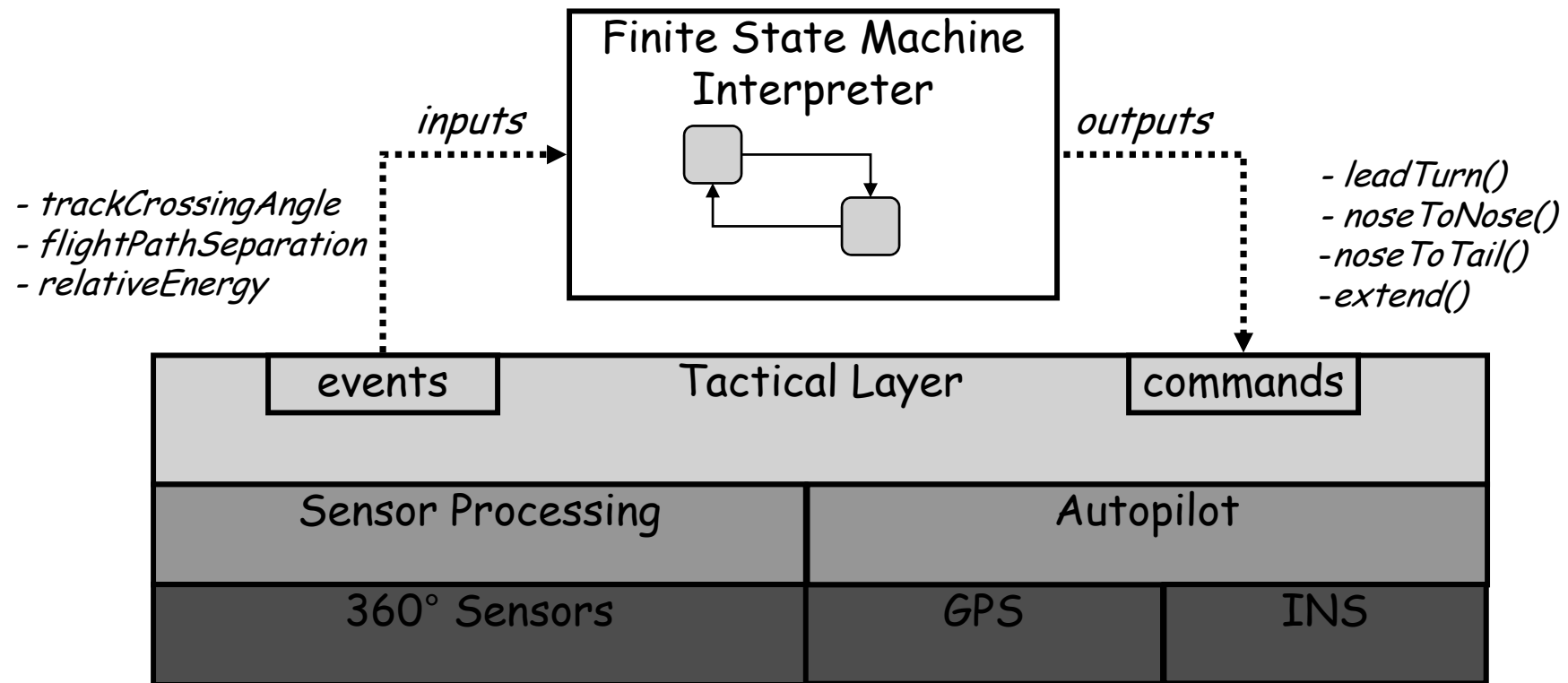
State Machine Example: Scissors



State Machine Example: Missile Avoidance



State Machine Autonomy Architecture



Design and Visualization Environment

The screenshot displays the ESD ExecSpec Designer interface. At the top, there is a playback control bar with buttons for play, pause, and stop, along with time and rate settings. Below this is a timeline view showing a simulation from 00:00 to 02:00. The main area is a state machine diagram for a TWTA (Traveling Wave Tube Amplifier). The diagram includes states such as IDLE, STANDBY, WARM, READY, SWAP_ANT, RADIATING, and OFF. Transitions between these states are labeled with events and actions. Annotations include red arrows pointing to the Design Palette on the right, the State Machine diagram, and the Current State (RADIATING) in the AttributeView. The AttributeView at the bottom right shows a table of attributes for the current state.

Timeline

Design Palette

State Machine

Current State

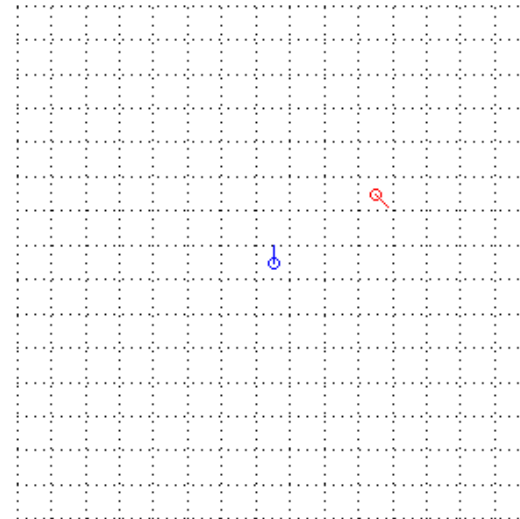
Inputs

Outputs

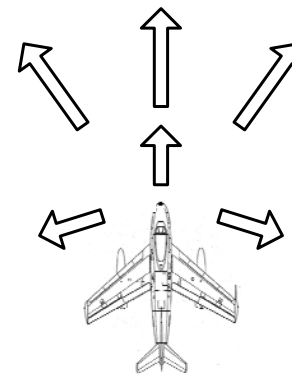
Attribute Name	Attribute Value
description	Traveling Wave ...
enabled	true
initial-state	INIT
name	TWTA

State Machine Verification: Model Checking

- **Mathematical methods can prove / disprove statements about state machines**
 - X can never happen
 - Y will always be true
- **Provides counterexample if statement is disproven**
- ***Both* the control logic *and* the plant dynamics must be modeled as state machines**
- **We use open-source NuSMV model checker**



**Relative
Geometry**



Maneuvers

Verifying Air-to-Air Tactics

■ Setup

- Identical aircraft
- Rear-quarter weapons only
- Head-to-head start

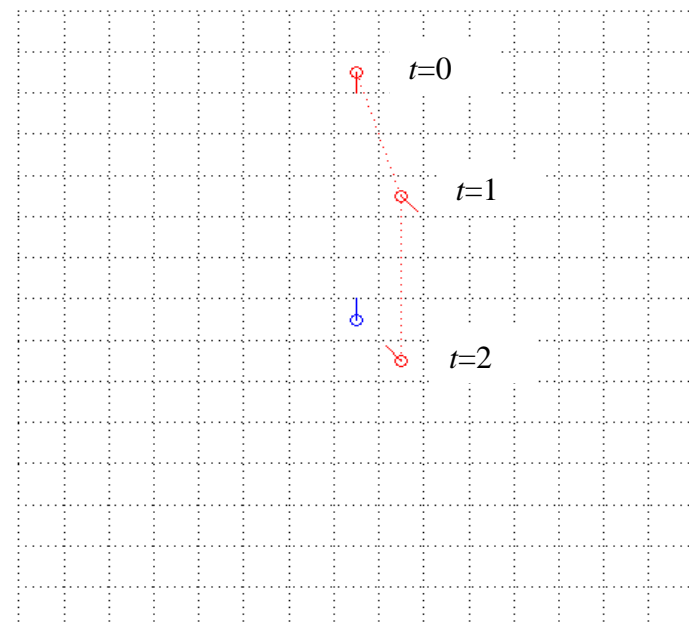
■ Tactics

- Copycat
- Mirror
- Copycat with Delay
- Mirror with Delay

■ Results

- Adversary *cannot* win against Copycat or Mirror without Delay
- Adversary *can* win against Copycat or Mirror with Delay
- Key factor: turn rate relative to time delay

Counter-example: Copycat with Delay



Time	Blue	Red
1	slow straight	fast left
2	fast left	slow right

Other Applications

- **Engagement Simulations**
 - Model threat aircraft avoidance maneuvers
 - Model contributions of Defensive Counter Air
- **Pilot Training**
 - Provide realistic simulated adversaries
- **Other Tactical / Doctrinal Arenas**
 - Air and missile defense
 - Electronic warfare

