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

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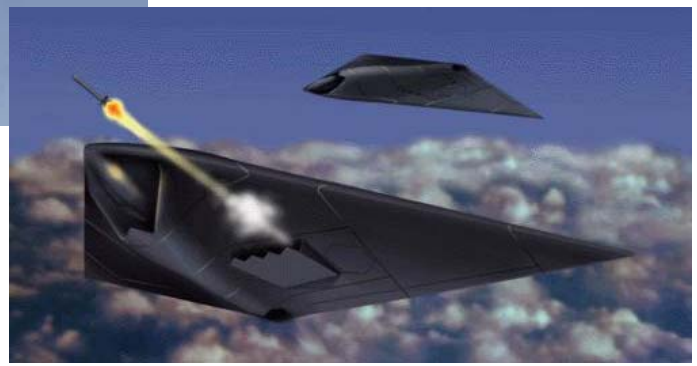
Evolution of Unmanned Military Aviation

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

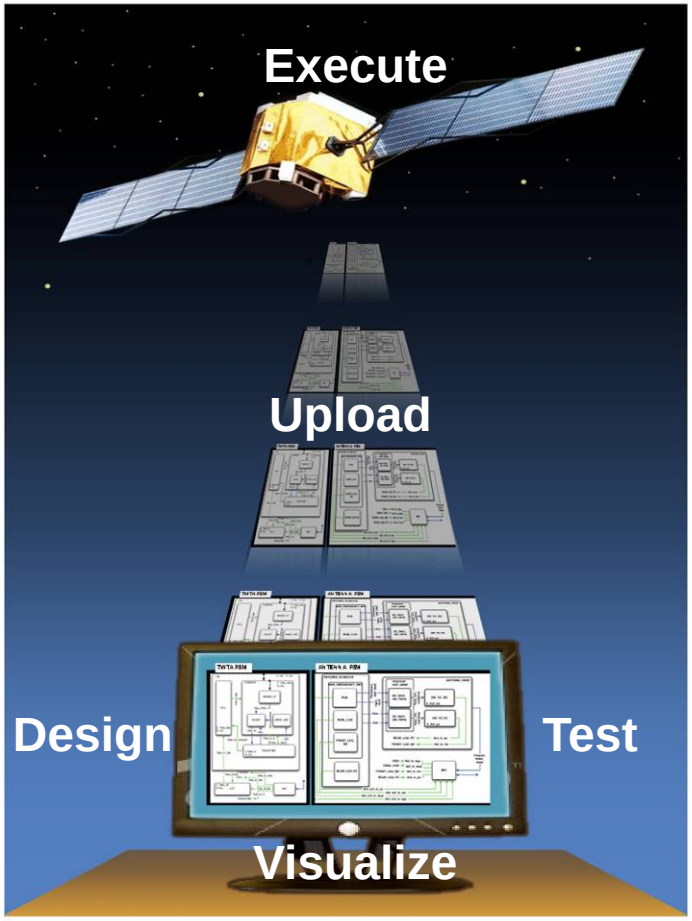
Put the Pieces Together

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

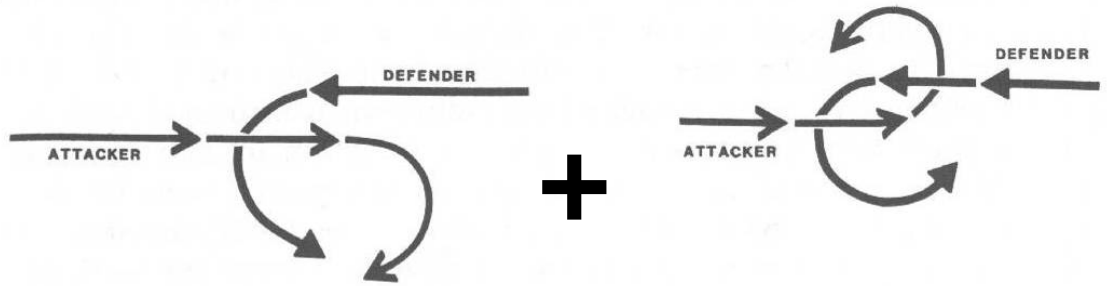


Representing Tactics as State Machines

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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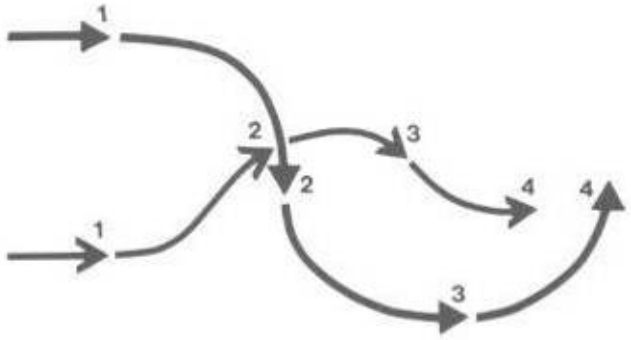

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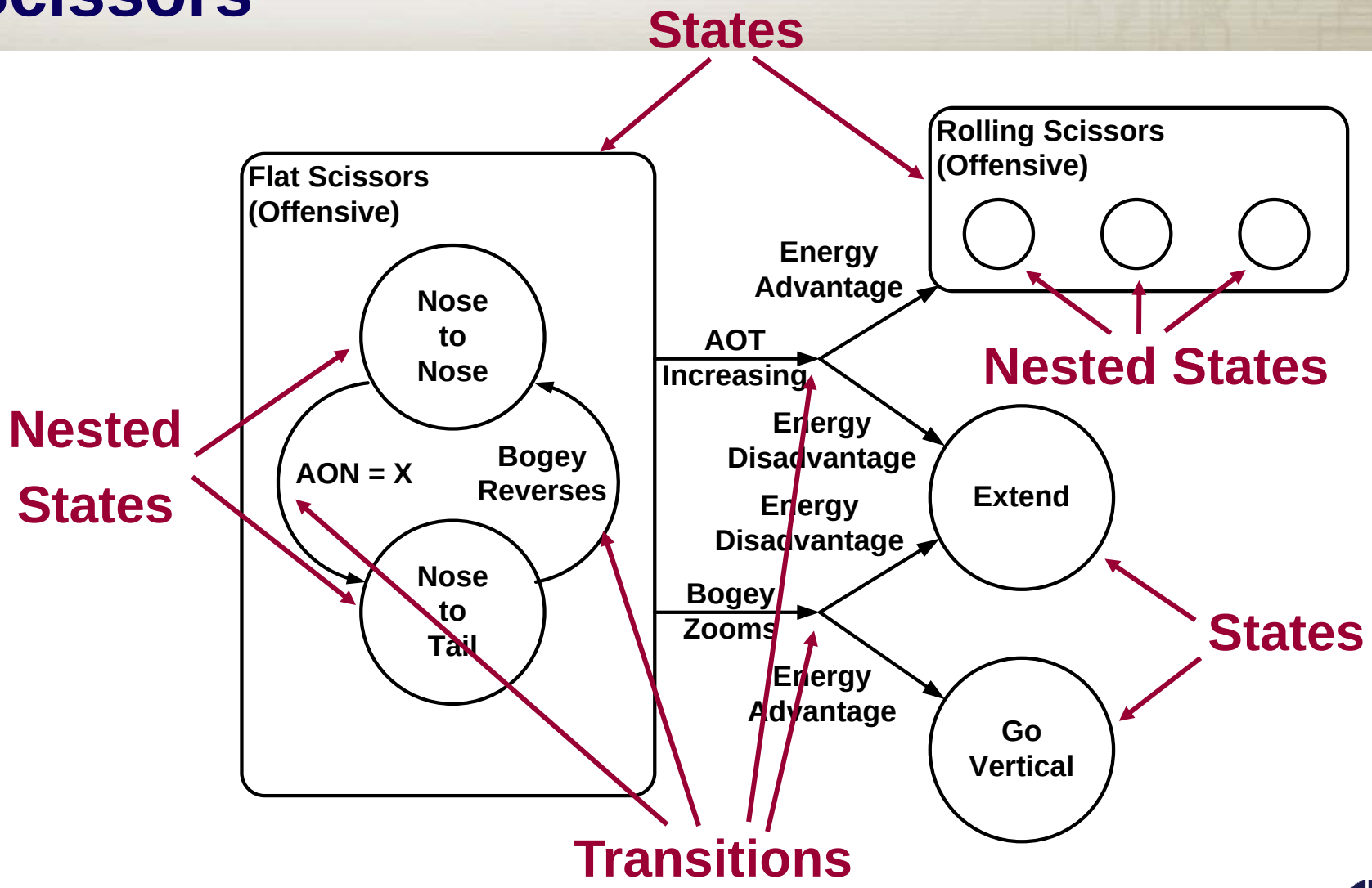
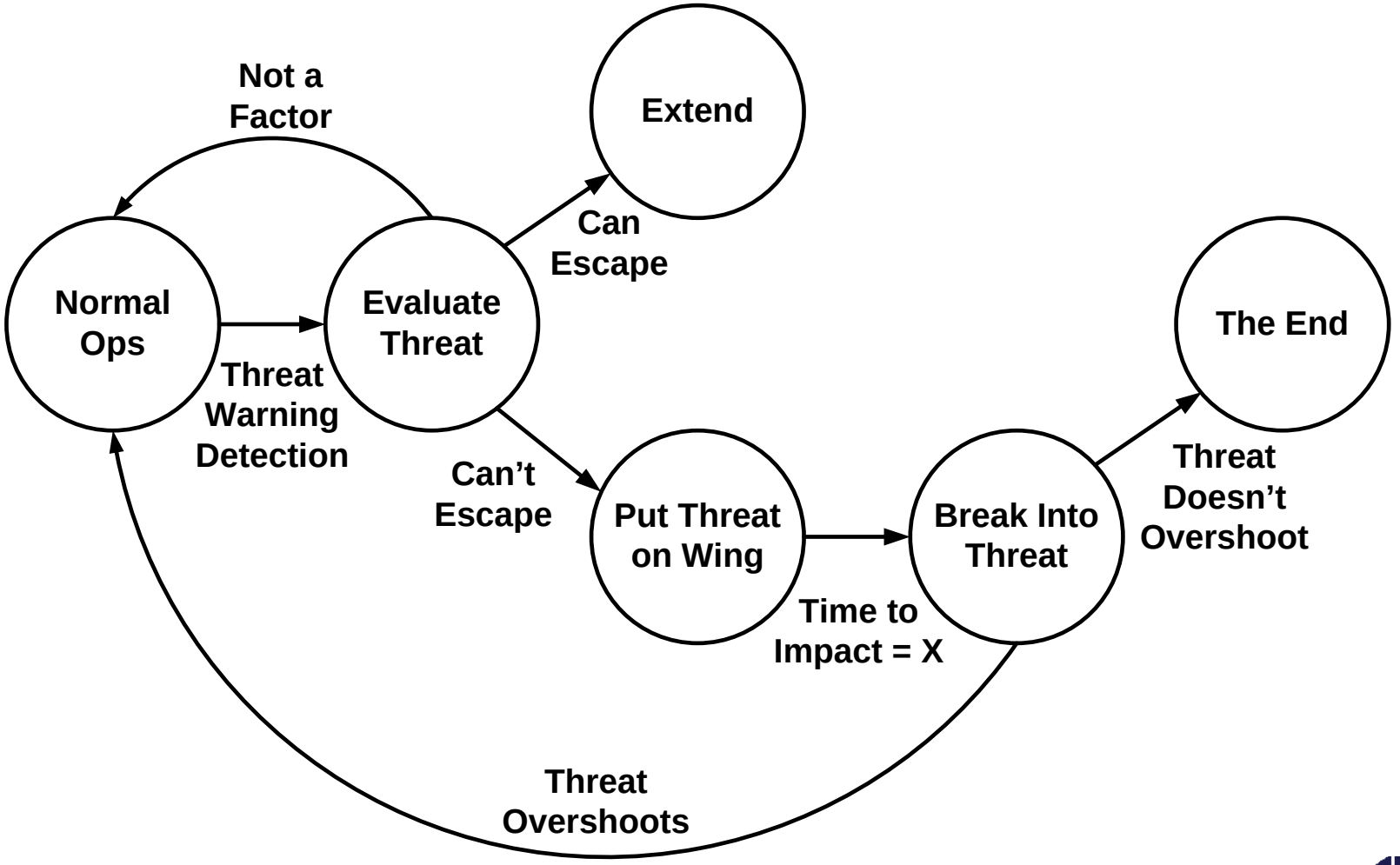
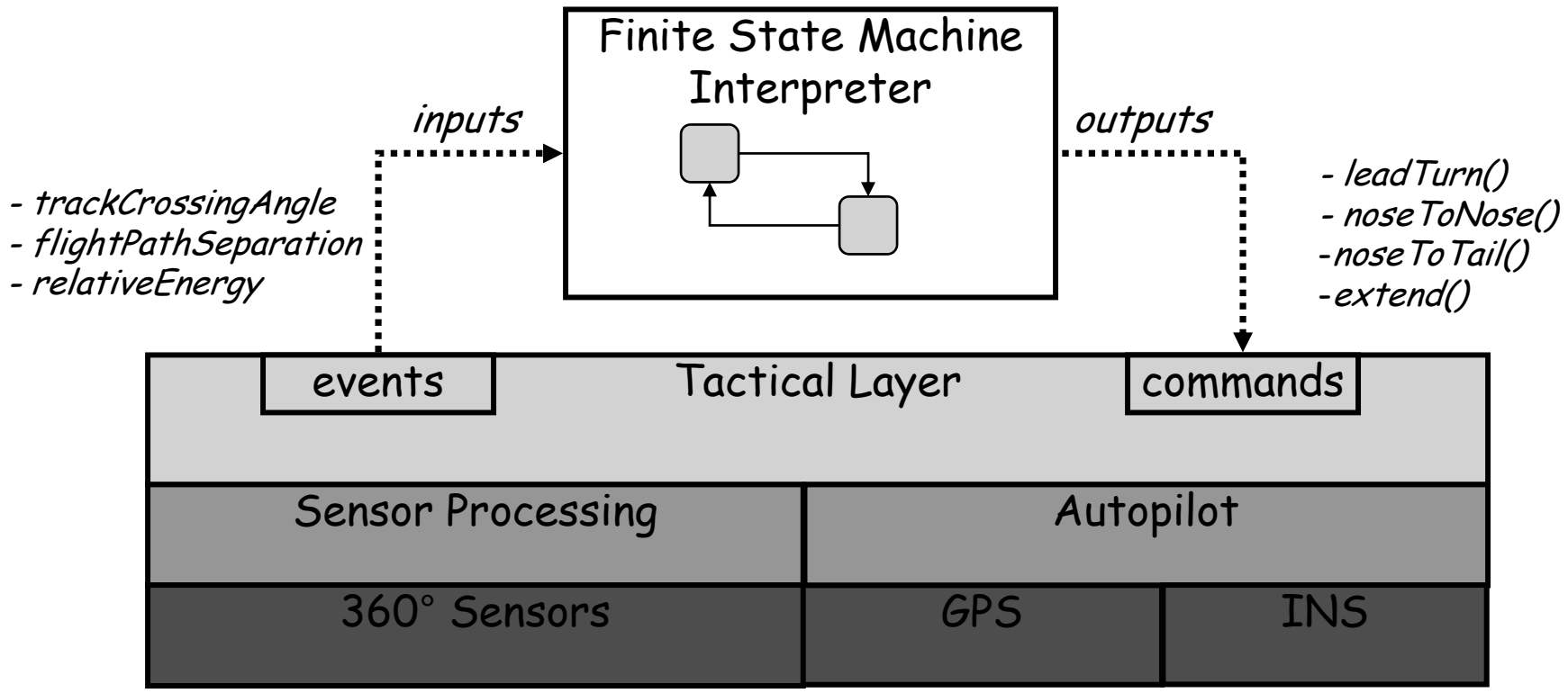
State Machine Example: Scissors



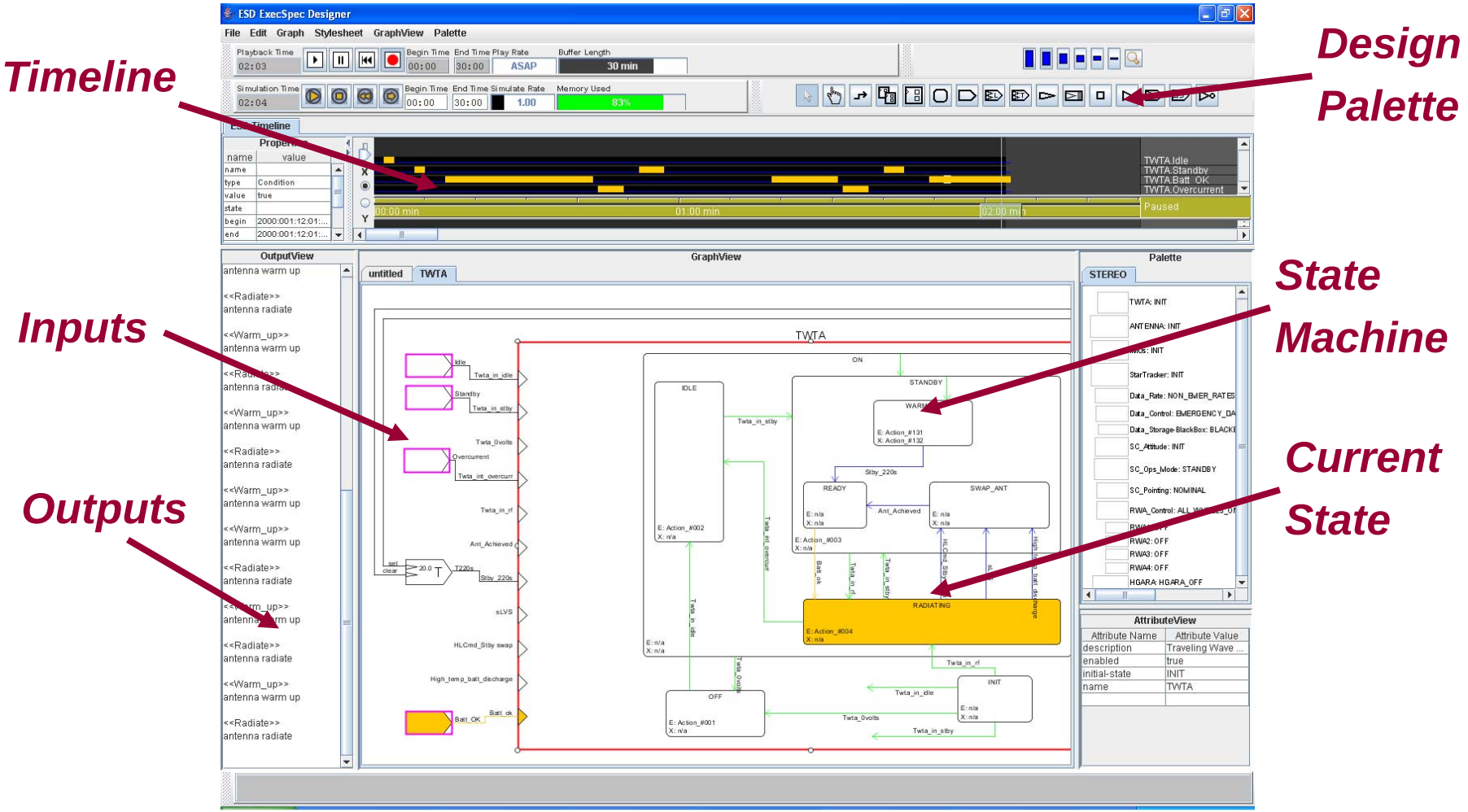
State Machine Example: Missile Avoidance



State Machine Autonomy Architecture

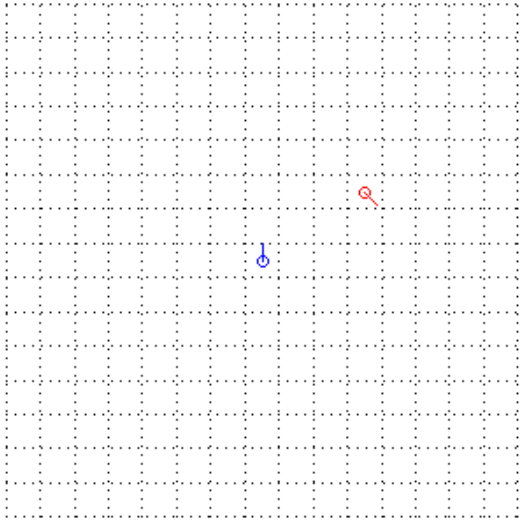


Design and Visualization Environment

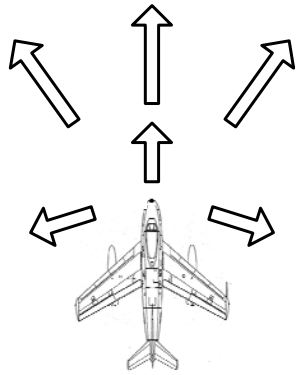


State Machine Verification: Model Checking

- 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

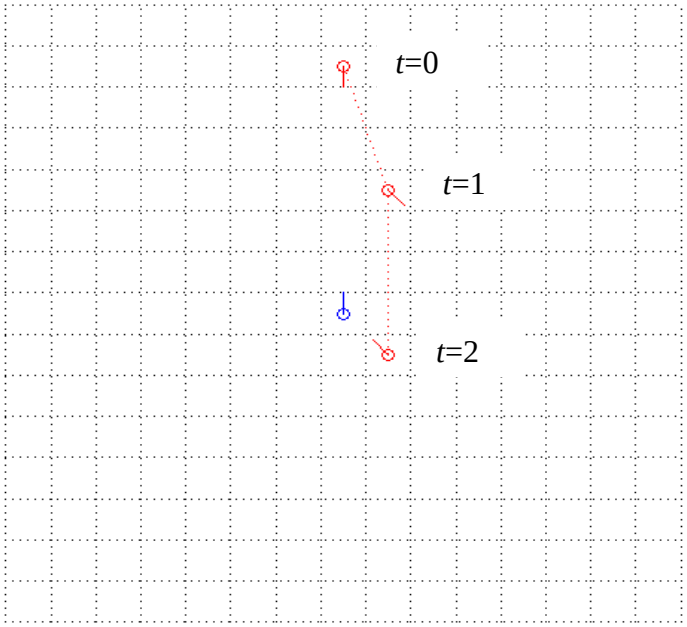


Maneuvers

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