Encounter-Based Simulation Architecture for Detect and Avoid Modeling

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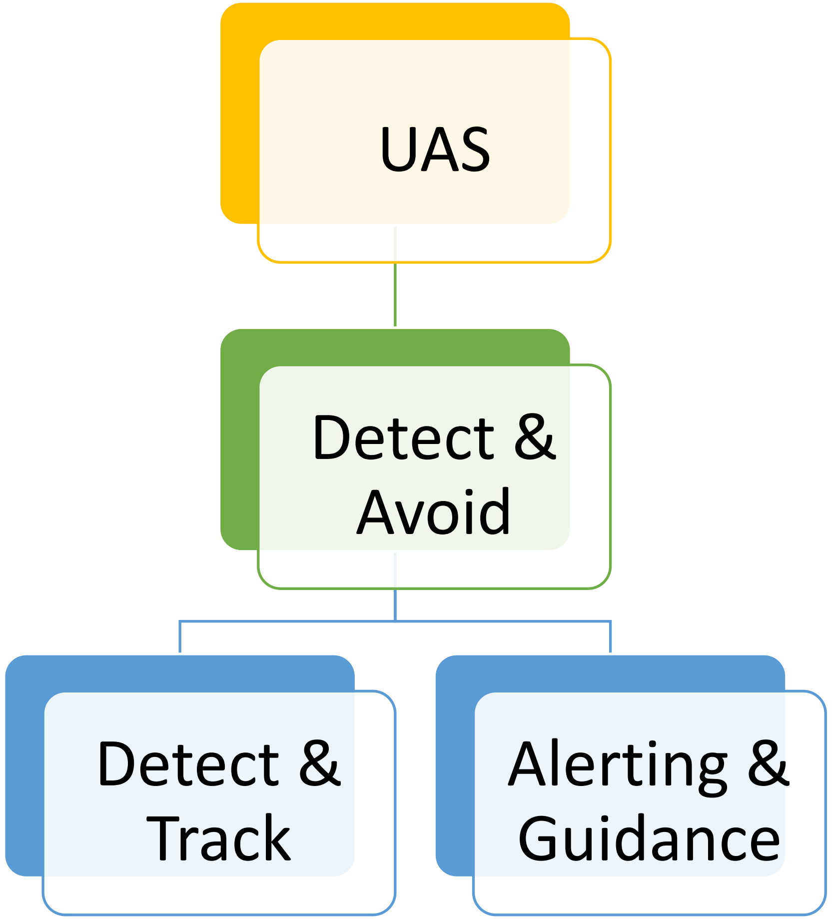
Motivation

Problem Domain



Unmanned Aerial Systems (UAS) Integration in the National Airspace System (NAS)

- Safe integration requires Detect and Avoid (DAA) Capability
- Two subsystems
  - Surveillance: Detect & Track
  - Alerting and Guidance

Research Needs

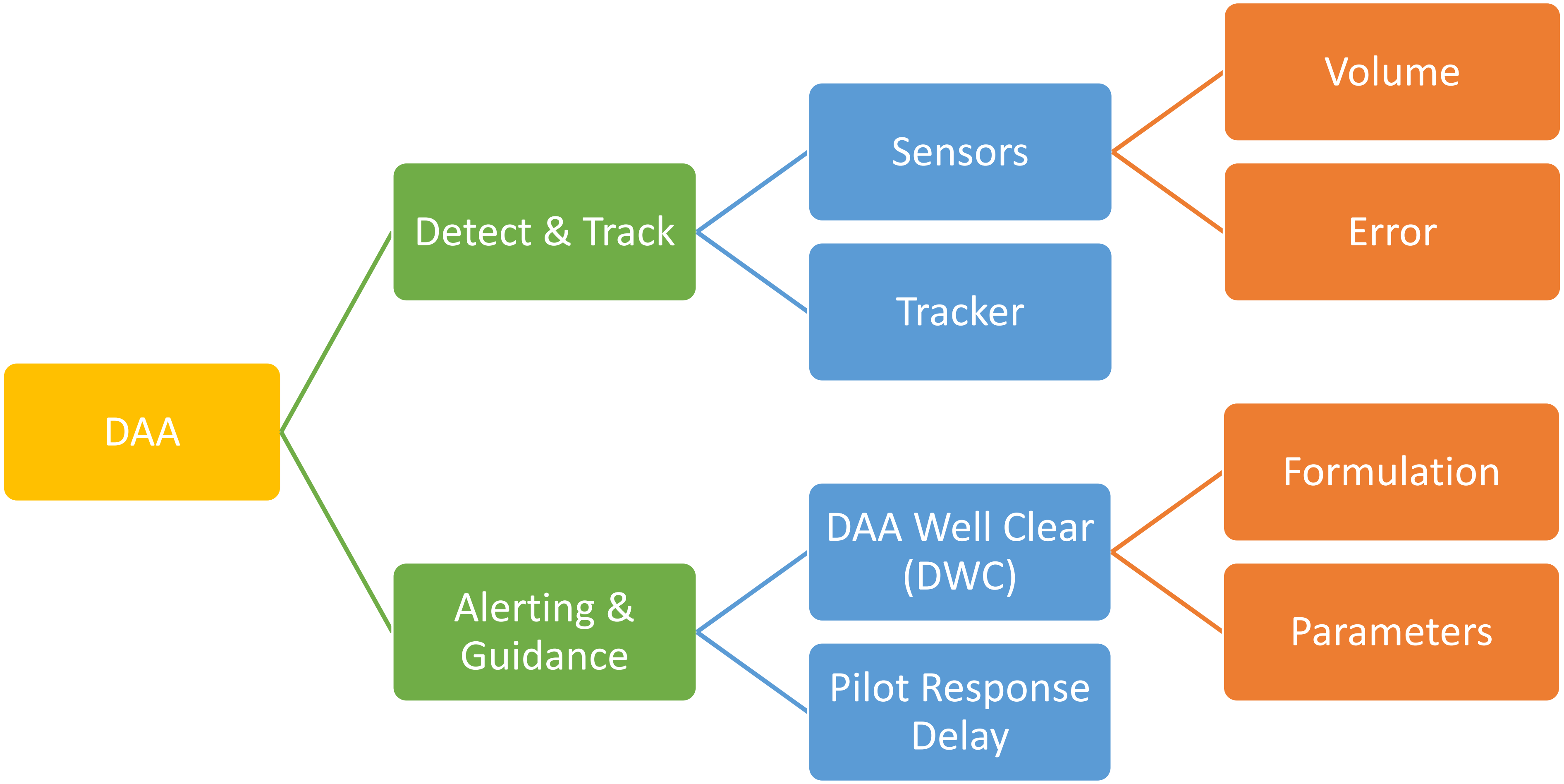
Research Activities

- Evaluate alternative concepts of operation
- Evaluate alternative separation standards
- Evaluate operational safety
- Evaluate impact on the National Airspace System (NAS)

Simulation and Validation

- Trade-space studies
- NAS-wide assessments
- Monte Carlo simulations
- Human-in-the-loop simulations
- Flight Tests

Research Challenge 1: Large Trade Space

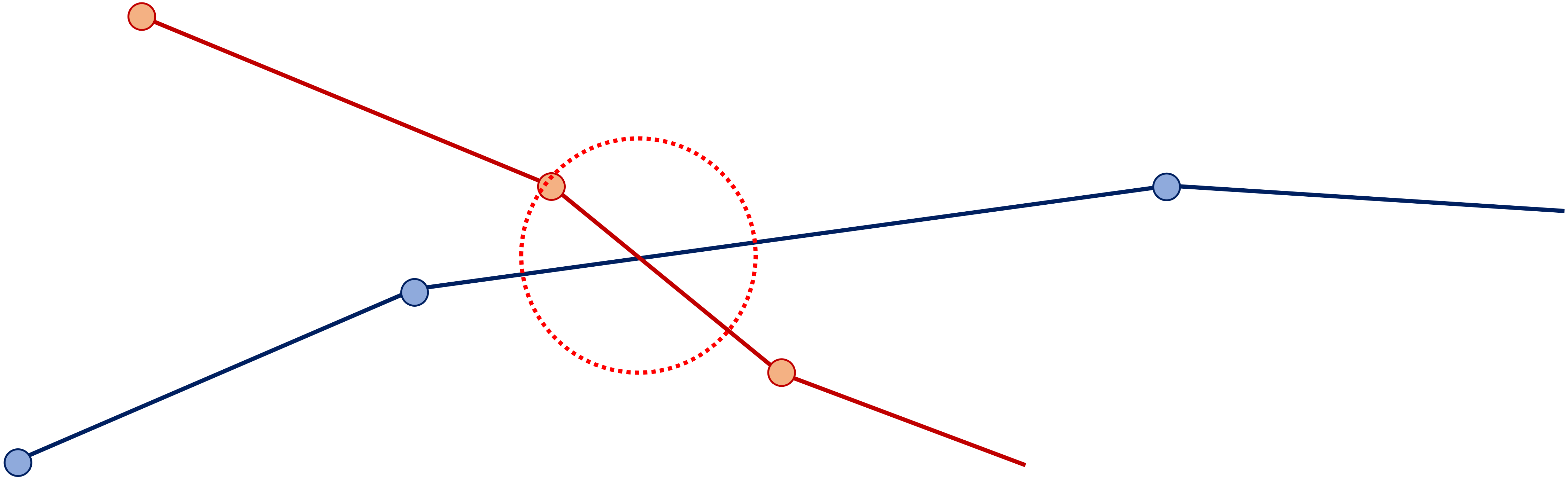


Research Challenge 2: Events of Interest Are a Small Fraction of Full NAS-wide data

- 27,000 UAS flights with a total 48,000 flight hours
- 30,000 VFR flights for a total 22,000 flight hours
- In the absence of avoidance maneuvers
  - 2,000 losses of well clear with a total duration of 25 hours
  - 50 near mid-air collisions (NMAC) with a total duration of 3 minutes
- So, why process 70,000 flight hours worth of data when we are only interested in 25 hours?
- Furthermore, foundational studies often require a subset of the data but data do not readily support pre-selection
  - Terminal area operations
  - Smaller unmanned vehicles: speeds < 100 knots & altitudes < 10,000 ft

Events of Interest

- Typically have very short duration
- End to end modeling of all flights is inefficient



Solution

- Identify flight pairs that are in proximity to one another: extract and save the proximal portions of their trajectories – these are called ***Encounters***
- Identify and select only those encounters that are relevant to a research study
- This is the genesis of the ***Encounter-Based Architecture***

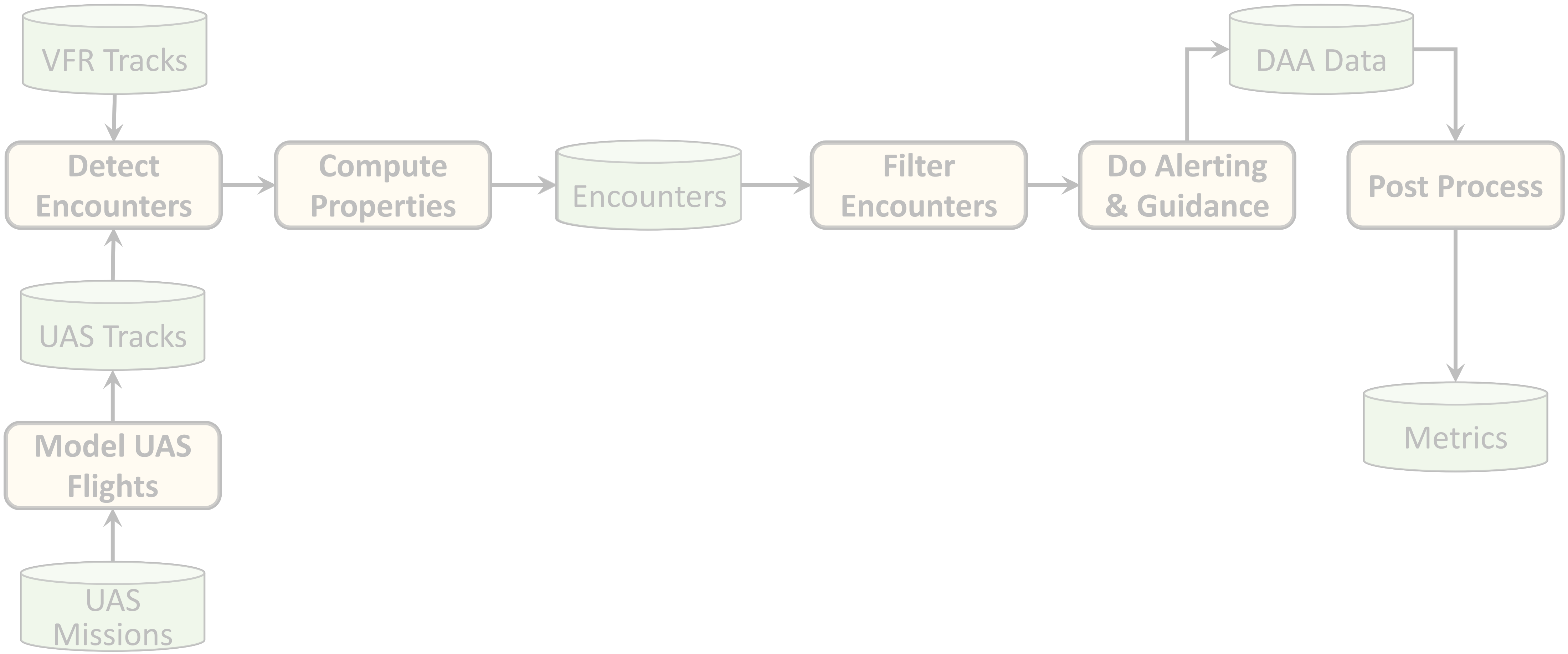
Benefits of this Approach

- Reduced data size
- Reusable standard encounters
- Repeatability since input data is fixed
- Easier comparison of alternative concepts
- Ability to identify and select subsets of encounters

Encounter-Based Architecture

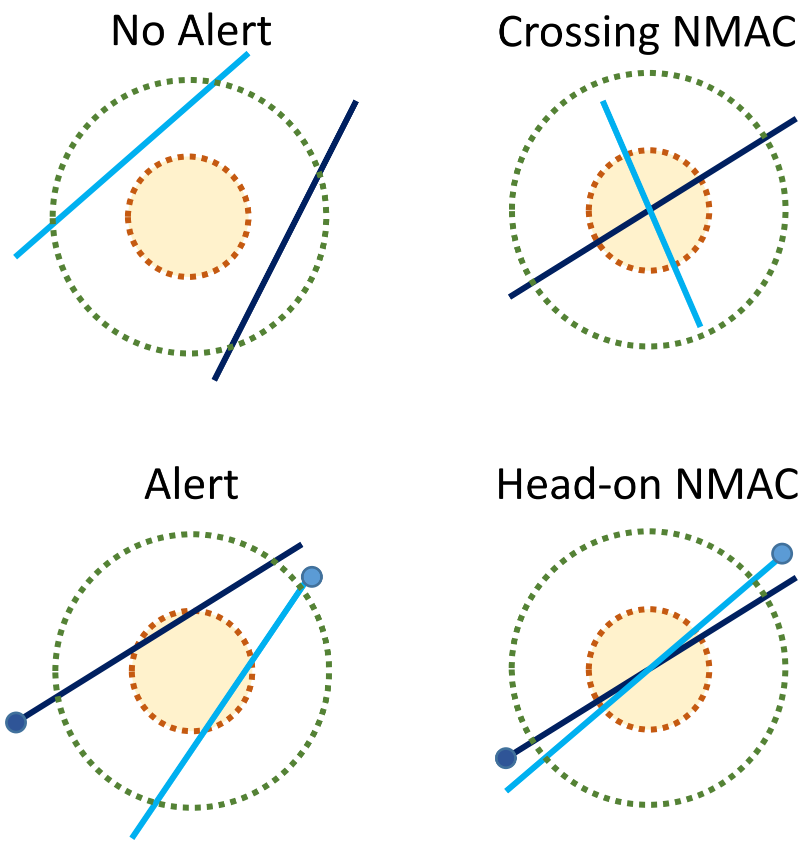
Pipelined Data Processing

Encounter-Based Data Processing



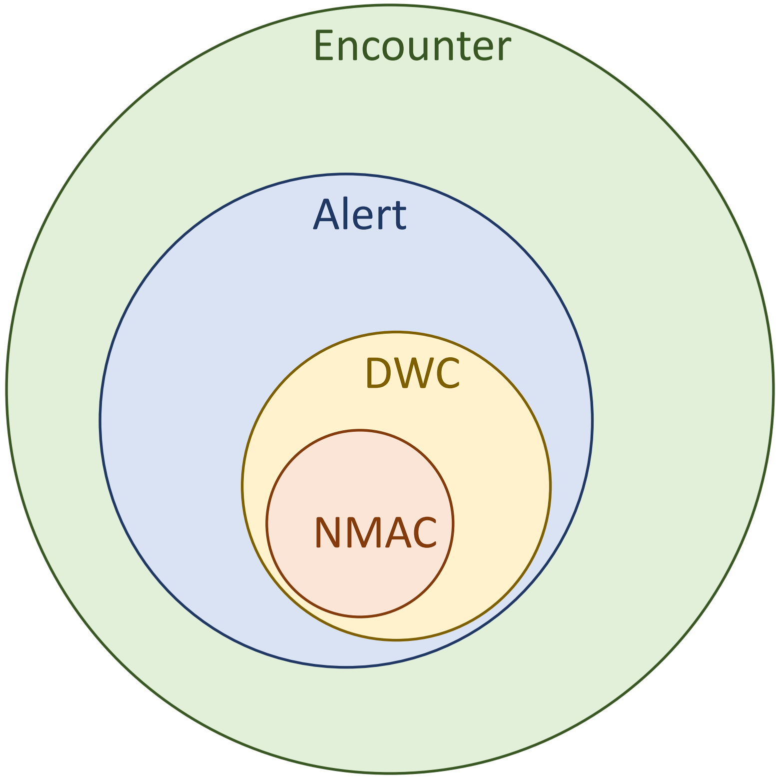
Encounter Detection

- Identify aircraft pairs that are in proximity. These can potentially
  - Alert, or
  - Lose separation, or
  - Violate the near mid-air collision volume (500 ft x 100 ft)
- Do so in a computationally efficient manner



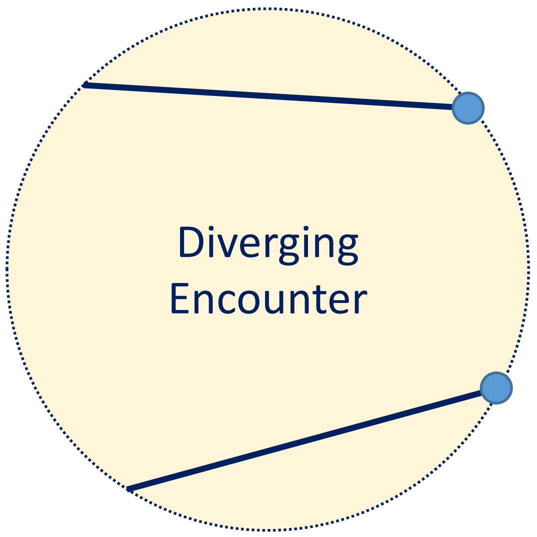
Encounter Detection Criteria

- Use simple efficient criteria to identify possible encounters
- Criteria must guarantee all events of interest are included
- Candidate: disc with radius *R* and height *H* centered on a UAS
  - Encounter starts when intruder enters the disc
  - Encounter ends when intruder exits the disc

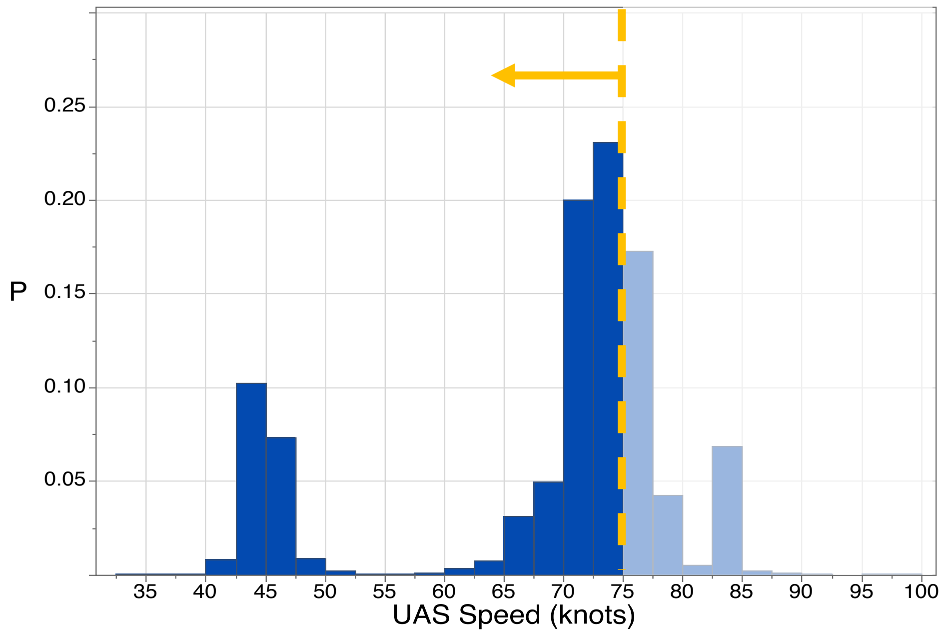


Selective Encounter Processing

- An encounter may not lead to an alert

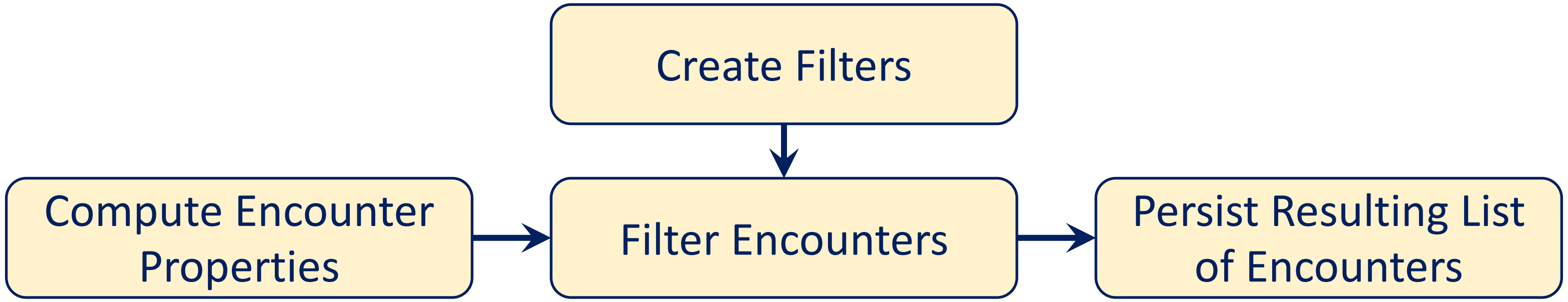


- An encounter may be out of scope



Solution: Property-Based Filtering

- Compute a set of properties for each encounter using aircraft data
- Create filters that reject encounters of no interest based on these properties
- Persist the list of remaining filtered encounters
- Use the filtered encounters in downstream processing



Encounter Properties

- DWC independent
  - Do not require DAA processing
  - Computed at encounter creation

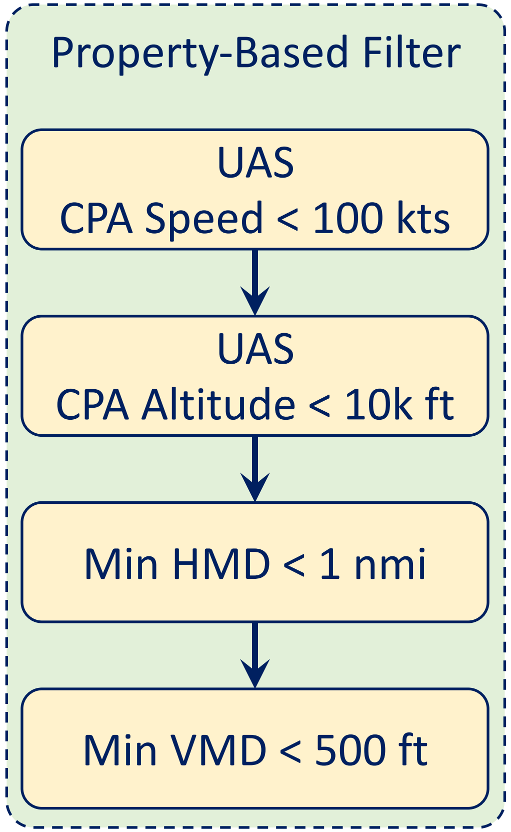
Encounter	Ownship	Intruder
ID	Callsign	Unique AC ID
Start Time	Aircraft Type	Min HMD/VMD
Duration		CPA Speeds
Weight		CPA Altitudes
		NMAC

- DWC dependent : Require DAA processing

Intruder.DWC
Unique DWC ID
Max Alert Level
Loss of DWC

Property-Based Filters

- Composited from predicates, which compare property values to constants
- Comparison operations:
  - Equality
  - Strict inequality
  - Non-strict inequality
  - List containment
- Boolean operators:
  - $\wedge$ (logical AND)
  - $\vee$ (logical OR)



Performance Comparison

End to End vs. Encounter-Based

Experiment Summary

Trade Space (96 configurations)

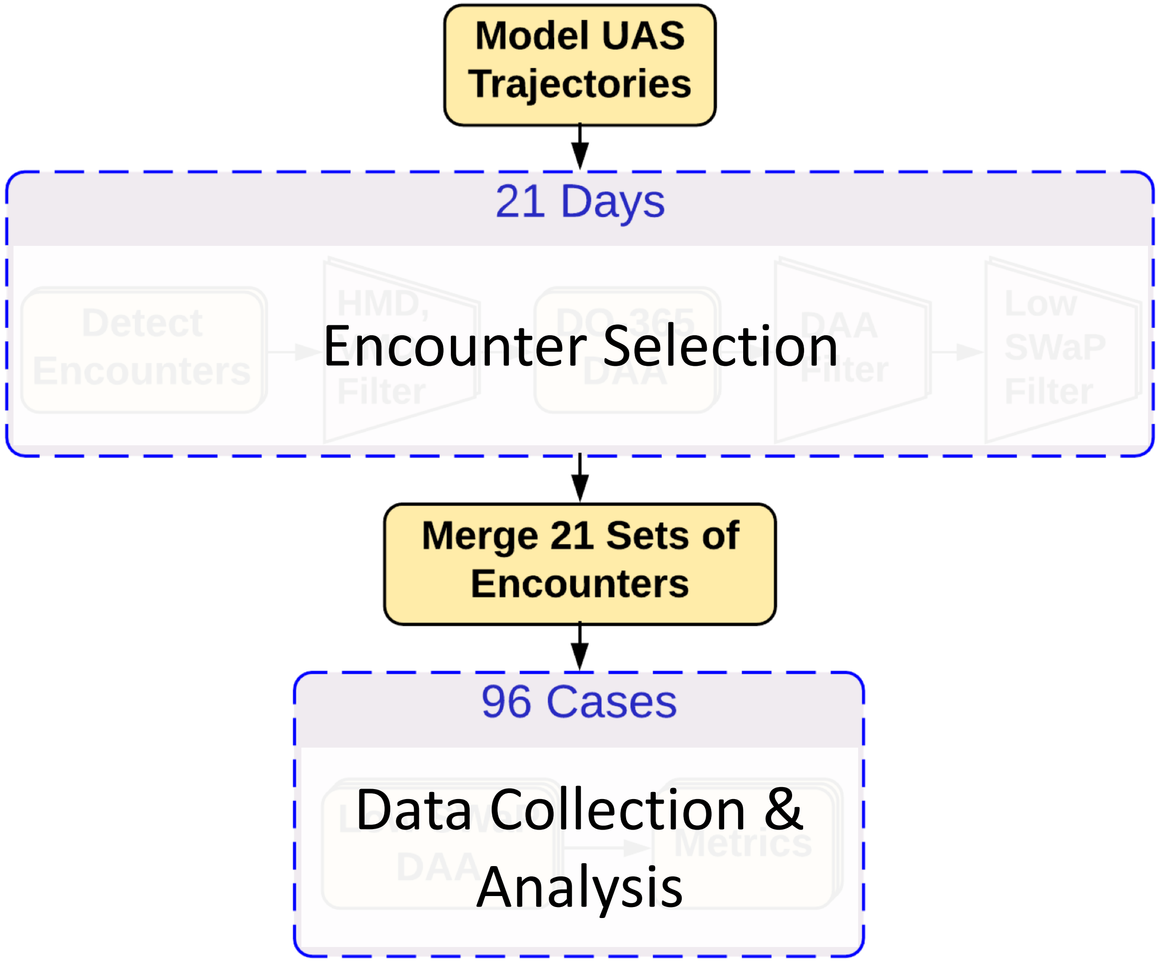
- 4 DWC candidates
- 24 sensor configurations
  - 6 detection ranges
  - 2 azimuths
  - 2 elevations

Setup (21 days)

- Light to heavy VFR traffic
- 27,000 UAS missions each day
- Encounter Detection Disc
  - R = 20 nmi
  - H = 10,000 ft

For more details please attend Dr. Wu's presentation tomorrow

Encounter-Based Data Processing



DO-365 DWC: A conservative DWC that encapsulates all four DWC candidates

Create and filter encounters for 21 days

- Using DO-365 DWC
    - Select encounters by filtering on min HMD/VMD properties
    - Compute DAA alerts
    - Select alerted encounters
- Select low speed and altitude encounters

- Runs parametric study: 4 DWC and 24 sensor configurations
- Generates final metrics

End to End Data Processing

- Full airspace-wide end to end simulation
- Flights are modelled from departure to destination
- Computational time is estimated
  - Measure for a single day simulation
  - Scale to 21 days
- Simulation results were compared to Encounter-Based approach for the same day: results were identical

Results

Computation Time

	Processing Stage	Total Time (hrs)
End to End	DAA Processing	3,651
	Metrics Generation	3,024
	Total	**6,675**
Encounter-Based	Flight Modeling	0.75
	Encounter Selection	78
	DAA Processing	346
	Metrics Generation	834
	Total	**1,259**

Encounter Selection

Processing Stage	# Input Encounters	# Output Encounters
Encounter Detection	–	**9,700,000**
HMD/VMD Filter	9,700,000	2,100,000
DAA Filter	2,100,000	130,000
Low SWaP Filter	130,000	**83,000**

Realized Benefits

- Reduced data size
  - Reduced flight time
  - Reduced number of encounters processed
- Reduced computation time
- Increased coverage of the trade space
- Standardized encounter suite
- Alternate encounter models supported

Summary

End to End Simulations

- Focused on full airspace modeling
- Departure to destination
- No means for selecting encounters to process
- Consumed significant resources

  ⇒ Sparse trade space coverage

Encounter-Based Architecture

- Tailored to suite research needs
- A priori encounter filtering
- Efficient use of resources

  ⇒ Better trade space coverage
- Standard encounter suite

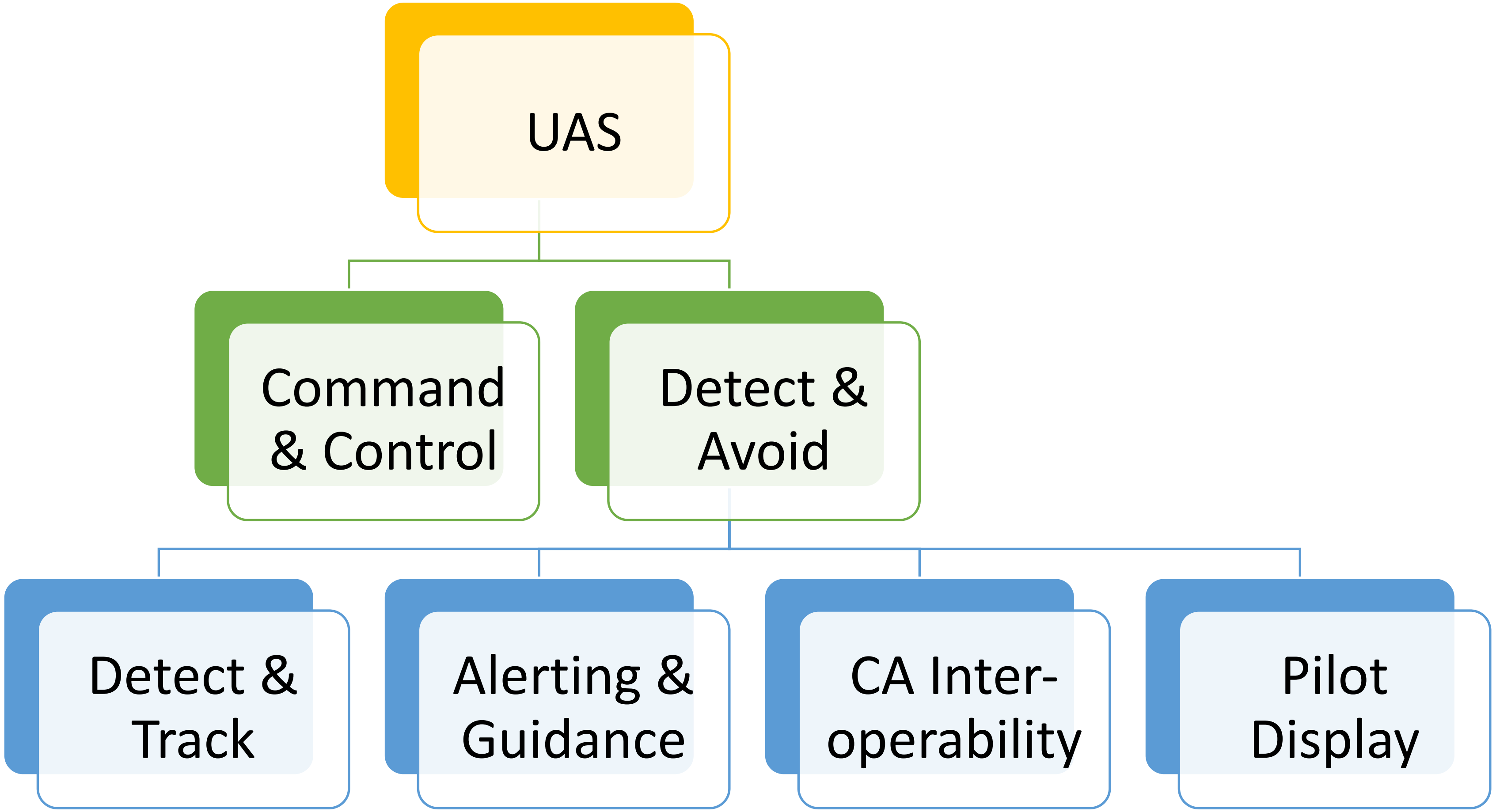
Future Work

- Next study is closed loop
  - Resolution and pilot delay
  - Surveillance uncertainty
- Performance enhancements
  - Post processing tool
  - Module optimizations
- Advanced architectures
  - Scalable architectures: concurrency and parallelism
  - Big Data architectures
  - GPU processing

Questions

Backup

Unmanned Aerial Systems Integration in the National Airspace System



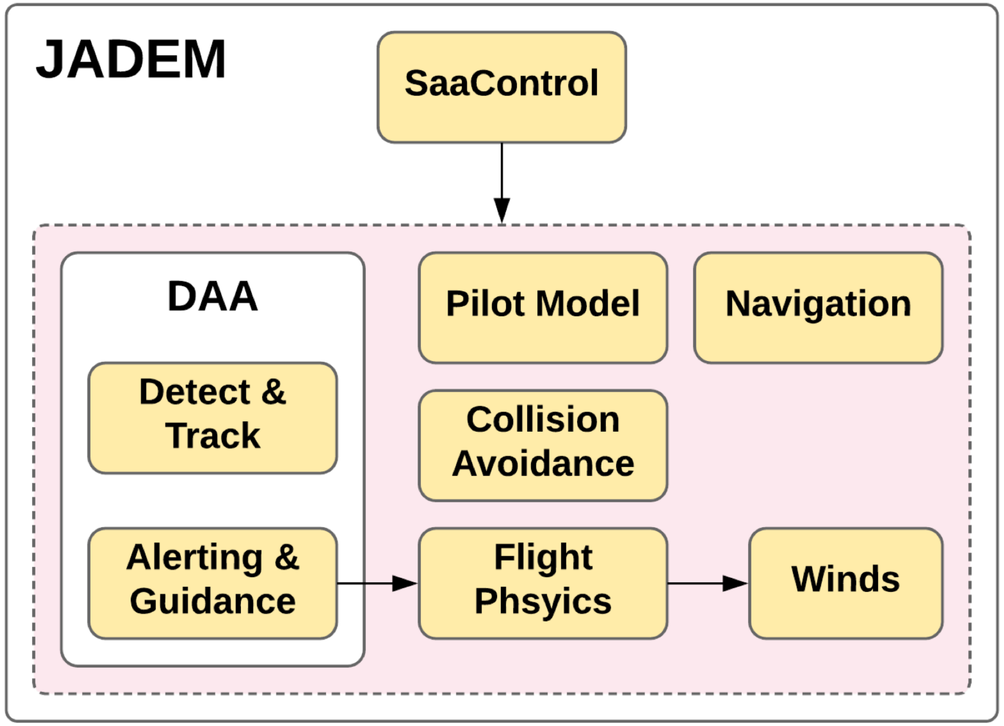
Data Sources: State of the Art

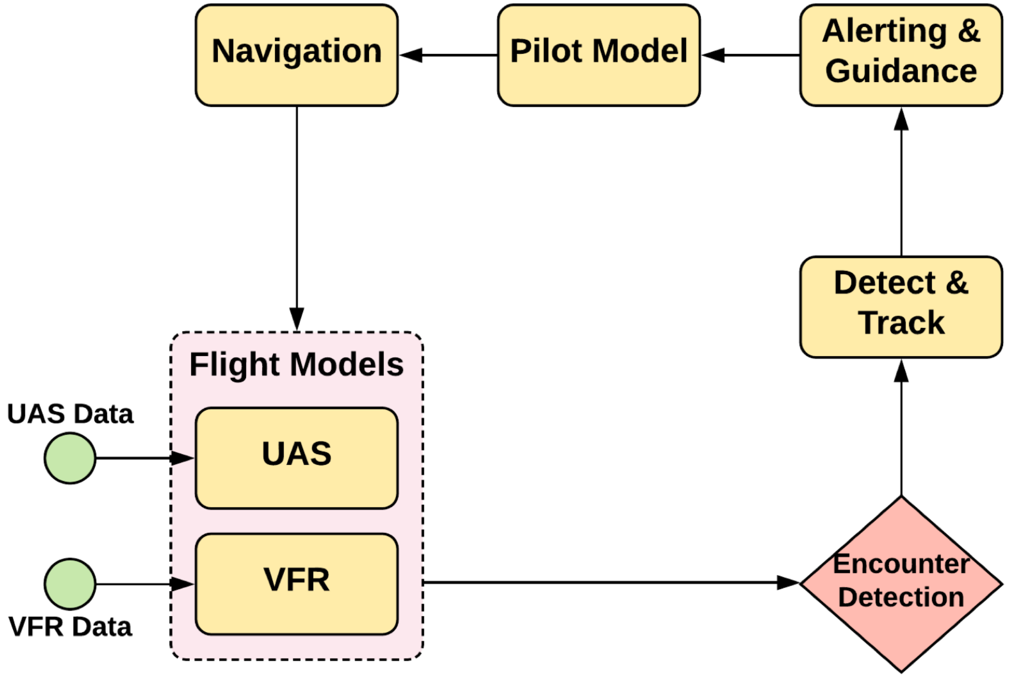
- VFR data: 84th Radar Evaluation Squadron (RADES)
- Three approaches currently in use
  - MIT encounter model: VFR-VFR
    - Create database of statistical features of VFR encounters
    - Create weighted encounters with same statistical characteristics as the VFR data
  - Parametric encounter model: Geometric
    - Create encounters by manipulating encounter variables
    - Speeds, altitudes, closest point of approach, etc.
  - NASA encounter model: UAS-VFR
    - Develop a set of UAS flights that represent today's view of future predicted missions
    - Use VFR data from 21 days in 2012 (light, medium, and heavy traffic)

Java Architecture for DAA Extensibility and Modeling (JADEM) – Prior Simulations

- A general purpose simulation tool
  - DAA concepts
  - Safety assessments
- Supports
  - Testing and validation
  - Parametric studies
  - NAS-wide assessments

JADEM

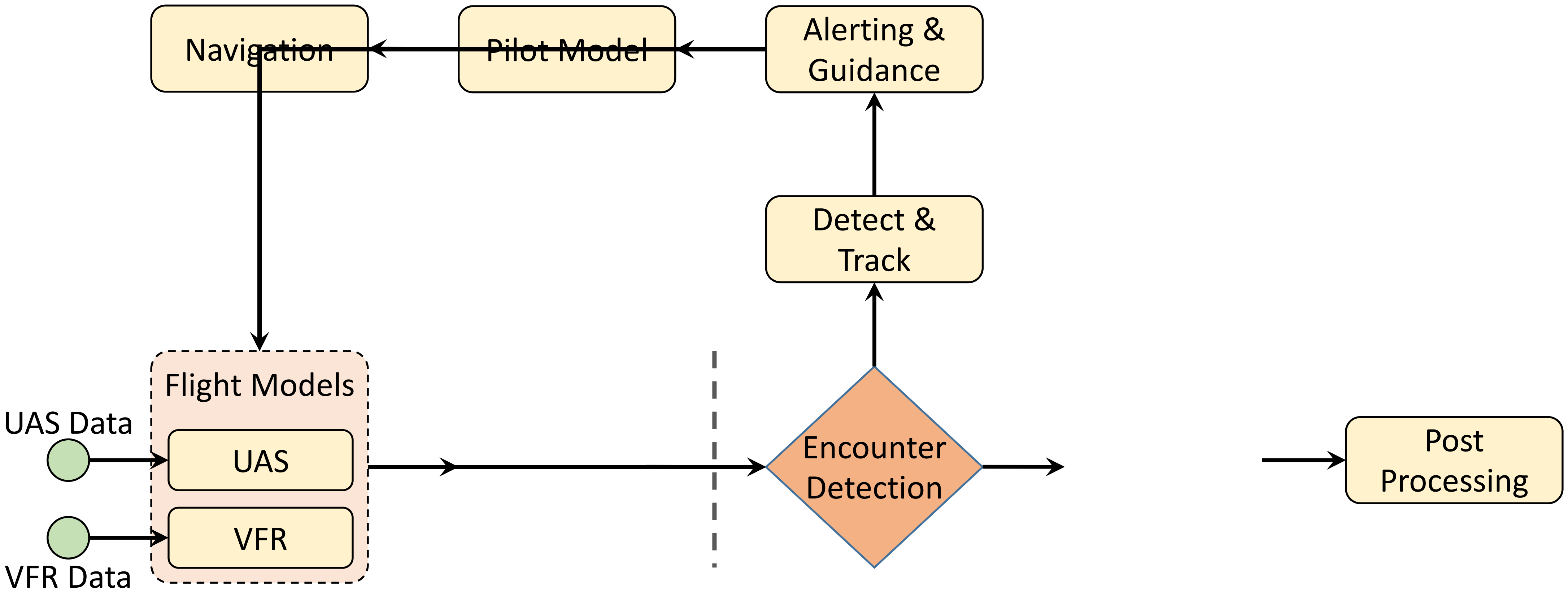

JADEM
SaaControl
DAA
Detect & Track
Alerting & Guidance
Pilot Model
Navigation
Collision Avoidance
Flight Phsyics
Winds


Navigation
Pilot Model
Alerting & Guidance
Detect & Track
Flight Models
UAS Data
UAS
VFR
VFR Data
Encounter Detection

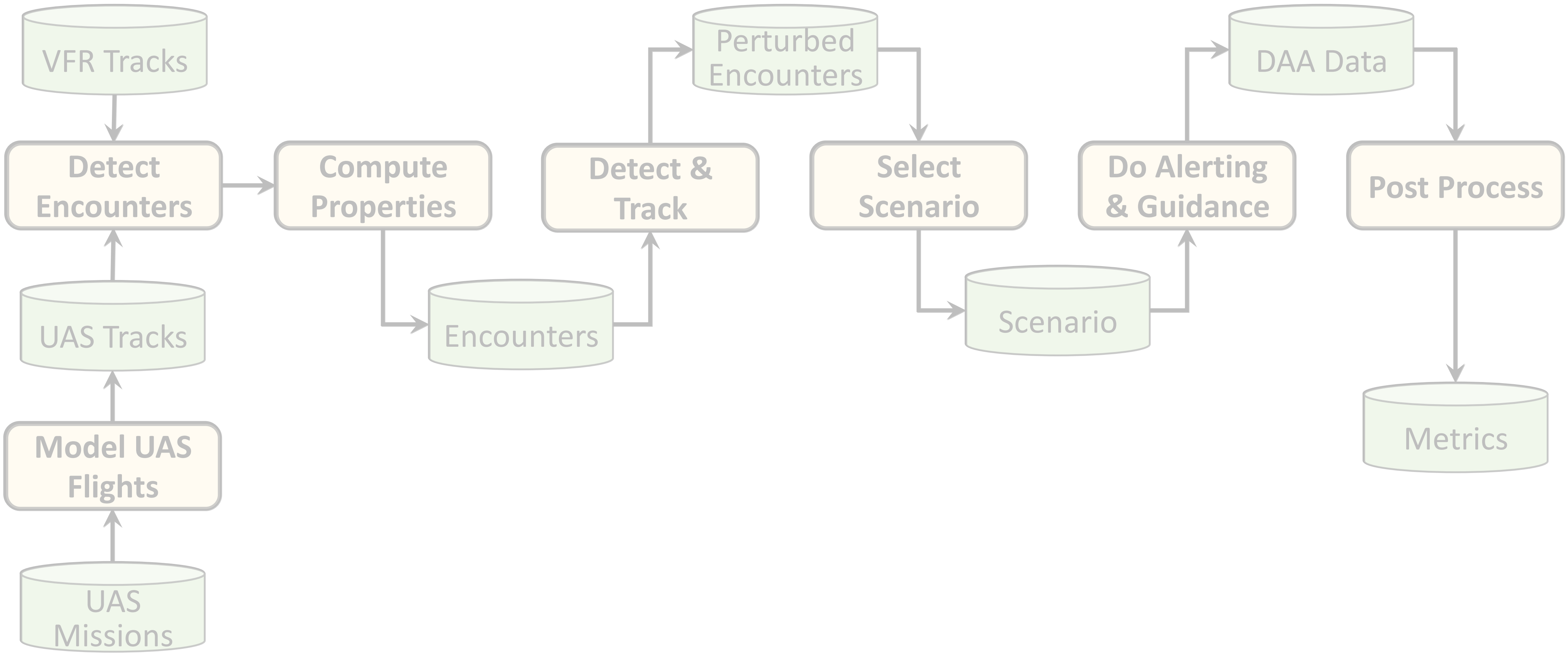
SaaControl Limitations

- Behavior is fixed in code
- Ingests and process all input data
  - A typical one-day scenario includes
    - 27,000 UAS flights and
    - 30,000 VFR flights, but only
    - 2,000 losses of well clear and
    - 50 near mid-air collisions
- Does not persist encounters in standard format
- Lacks mechanism to select types of encounters to be processed

Encounter-Centric Viewpoint



Processing Pipeline: Modular & Composable



Encounter Detection – Alerting Structure

- Separation Criteria
  - Spatial
    - vertical range
    - horizontal miss distance (predicted minimum horizontal range)
  - Temporal: modified tau
- Alerting Time: an alert is declared no earlier than a given threshold

Name	Buffered Well Clear Criteria	Alerting Time Threshold
Warning Alert	$DMOD = HMD^* = 0.75$ nmi $Z_{THR} = 450$ ft $T_{mod} = 35$ s	25 s ($t_{CPA} \sim 60$ s)
Corrective Alert	$DMOD = HMD^* = 0.75$ nmi $Z_{THR} = 450$ ft $T_{mod} = 35$ s	55 s ($t_{CPA} \sim 90$ s)
Preventive Alert	$DMOD = HMD^* = 1.0$ nmi $Z_{THR} = 700$ ft $T_{mod} = 35$ s	55 s ($t_{CPA} \sim 90$ s)

Thresholds for Detecting Encounters

- Alerting structure defines temporal thresholds equivalent to time to CPA (t_{cpa})
- Maximum range occurs with a head-on encounter
  - $R = t_{cpa} \times \Delta V_{max}$
  - Given *R*, slower approach speeds mean longer encounter duration

t_{cpa}	ΔV_{max}	$\Delta V_{\perp}$	R	H
90	600 knots	6,000 fpm	15 nmi	9,000 ft

Encounter Detection – Optimizations

- Data is processed in time windows (typically 5 minutes)
- Grid method
  - Map intruder positions for each processing window to a fixed horizontal grid
  - Cell size is obtained from window size and maximum approach speed
- Leap-frog through the time series
  - Assume intruder and ownship are head-on: $\Delta V_{max} = |V_1| + |V_2|$
  - Calculate interval to skip: $\Delta t = (range - R) / \Delta V_{max}$

Encounter Specification

- 1 UAS
- 1 intruder
- Time Series
  - Positions
  - Velocities
- Encounter Properties

Scenario Selection