USING GAME THEORY TO ASSESS THE STRENGTH OF AN AV SYSTEM AGAINST EVOLVING OFFENCES

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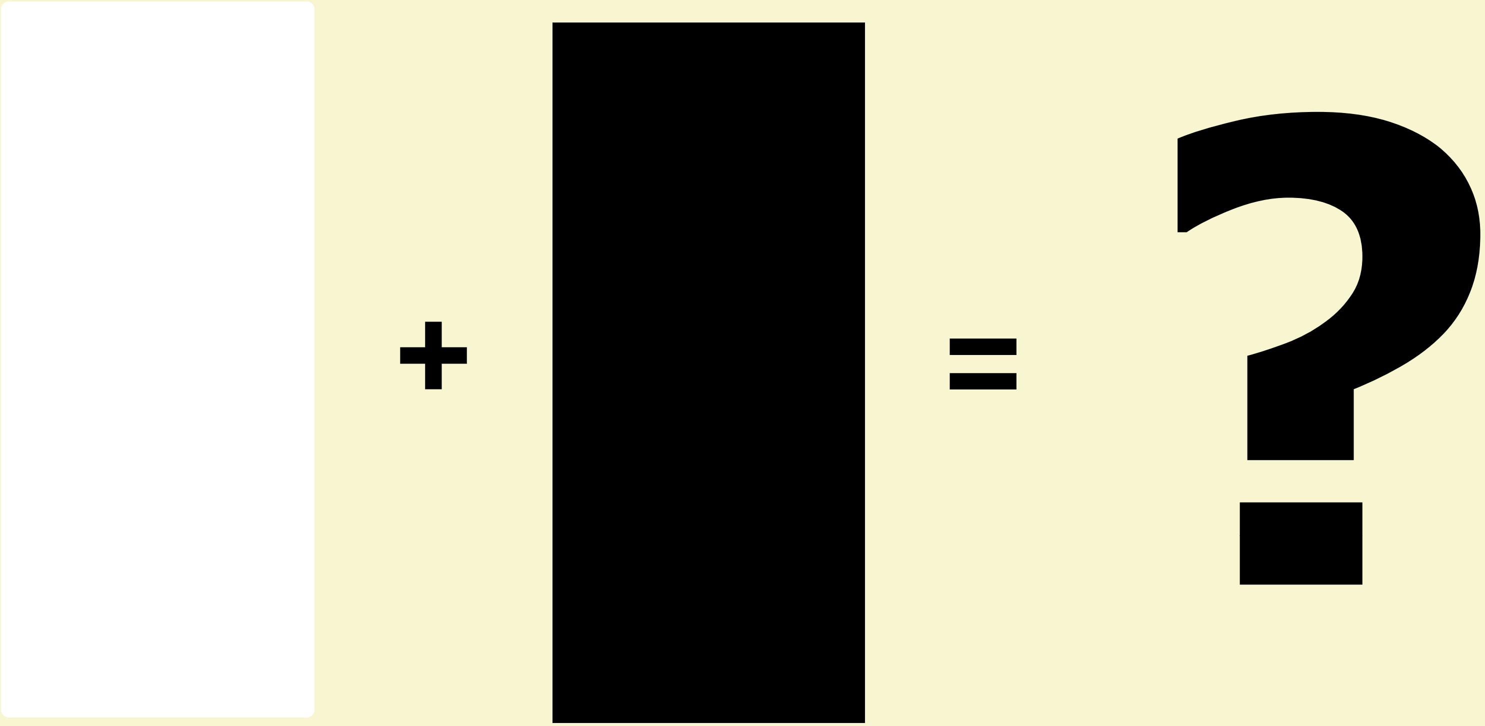
White List + Black List = ?



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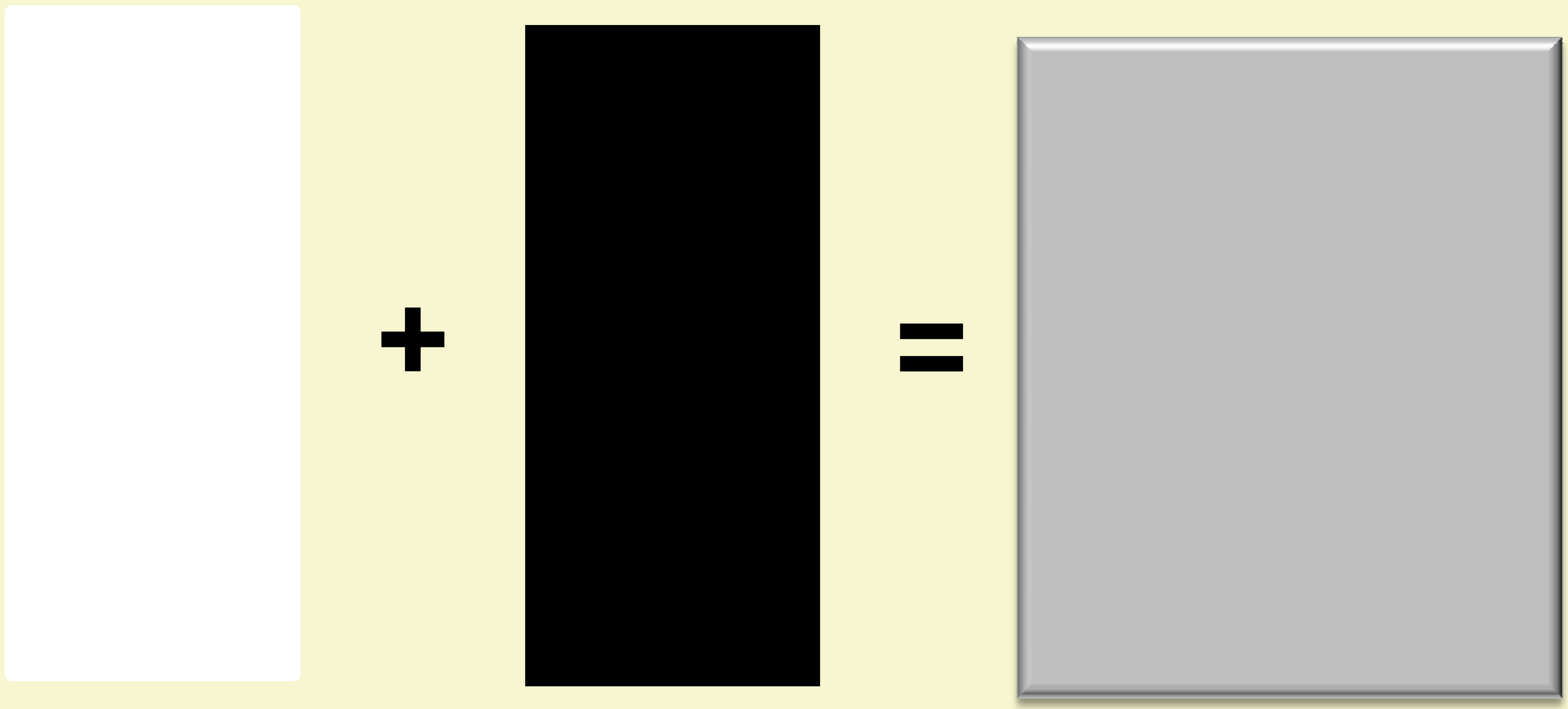

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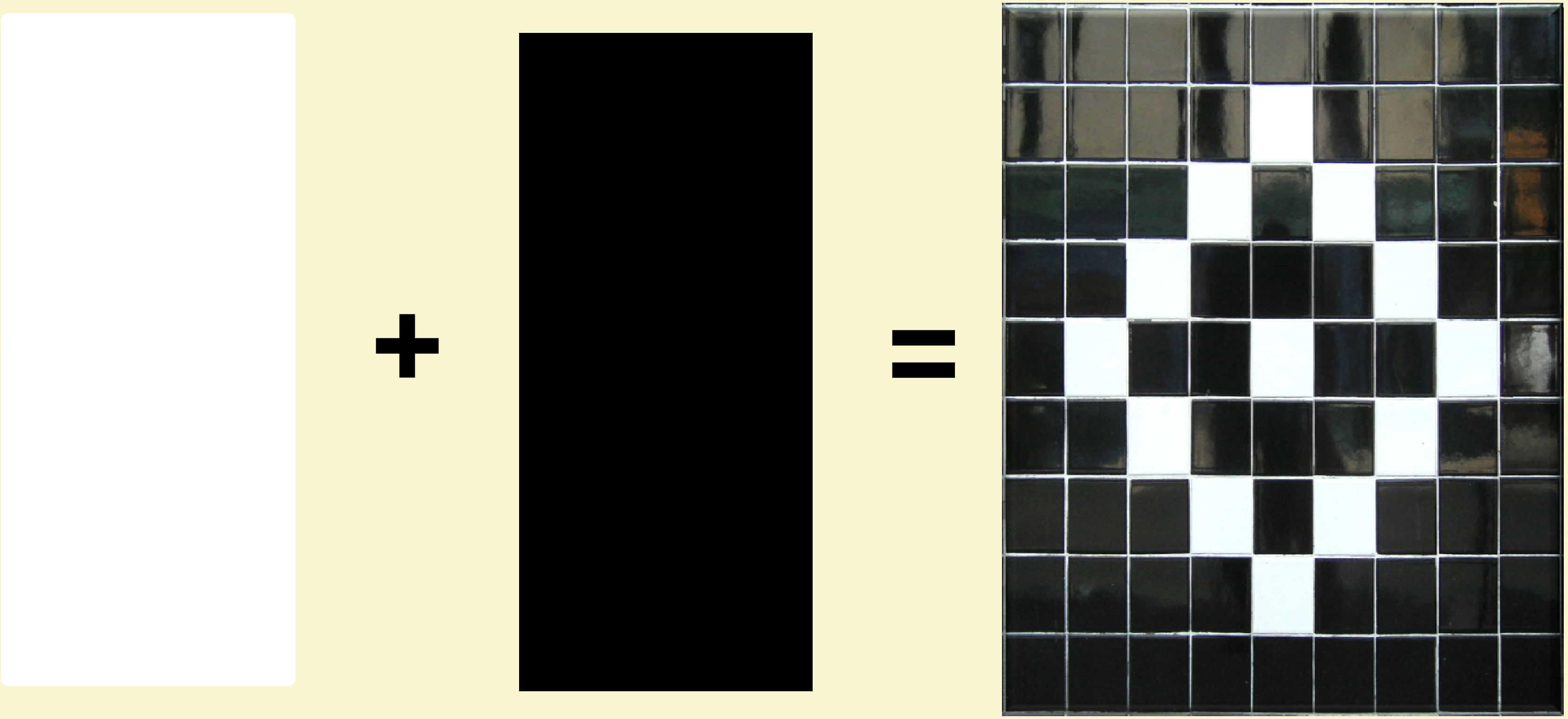

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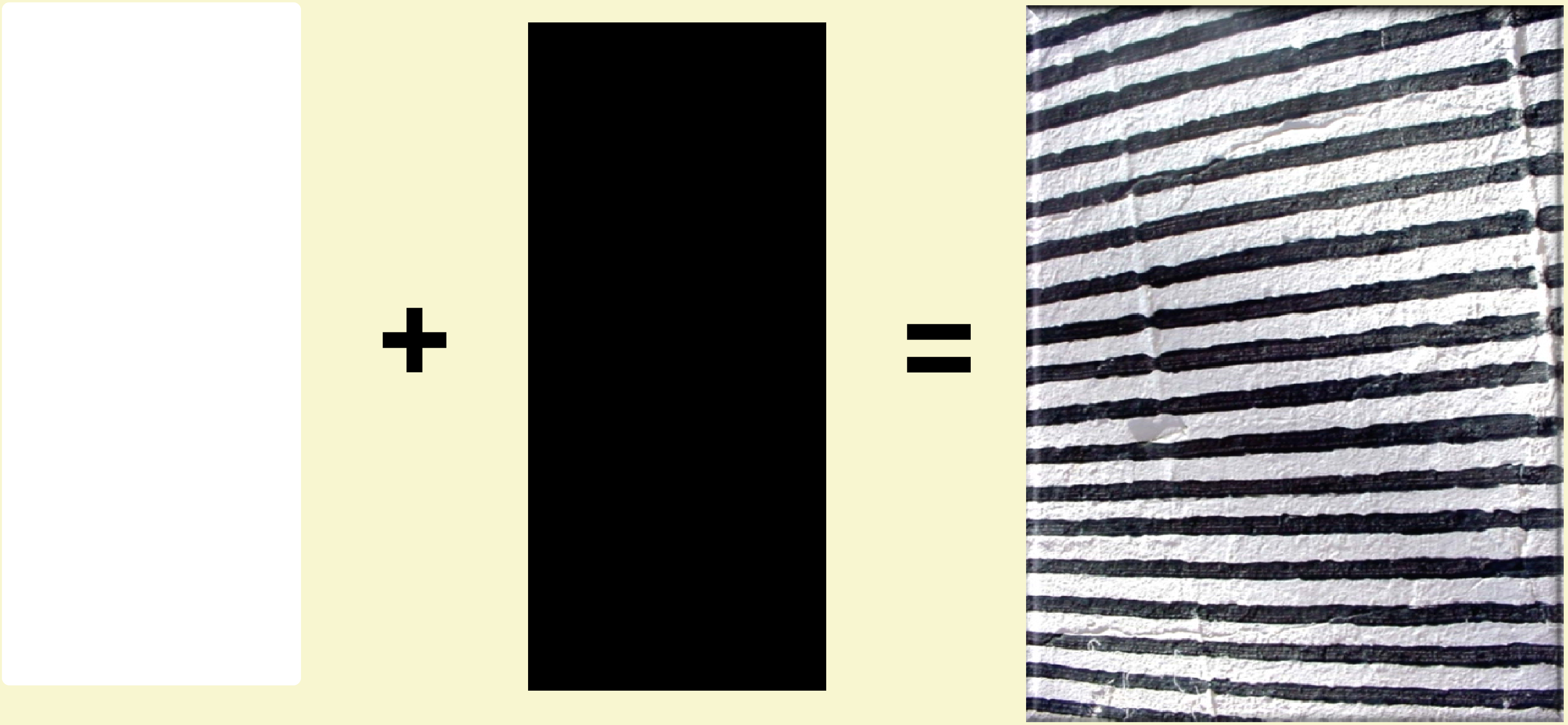

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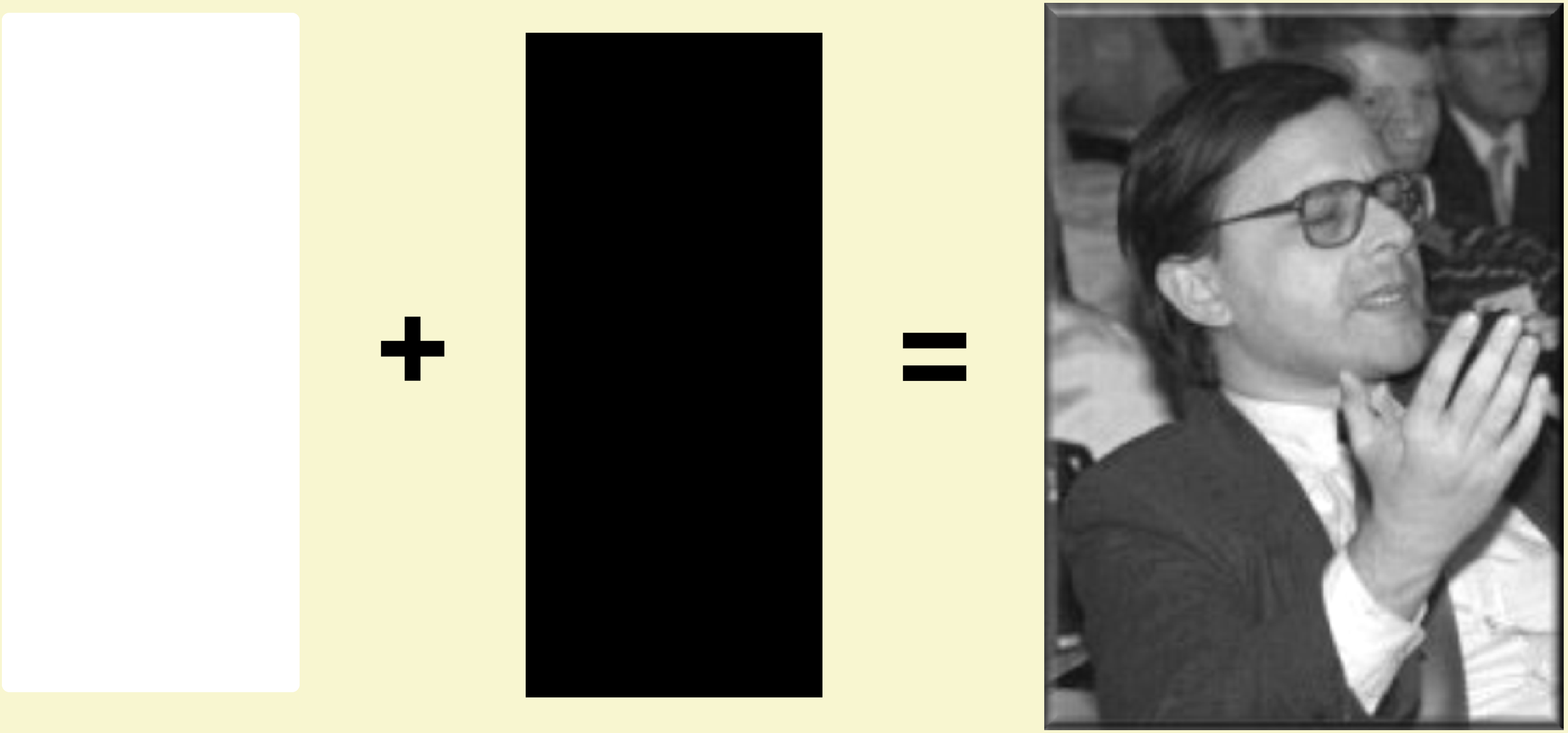


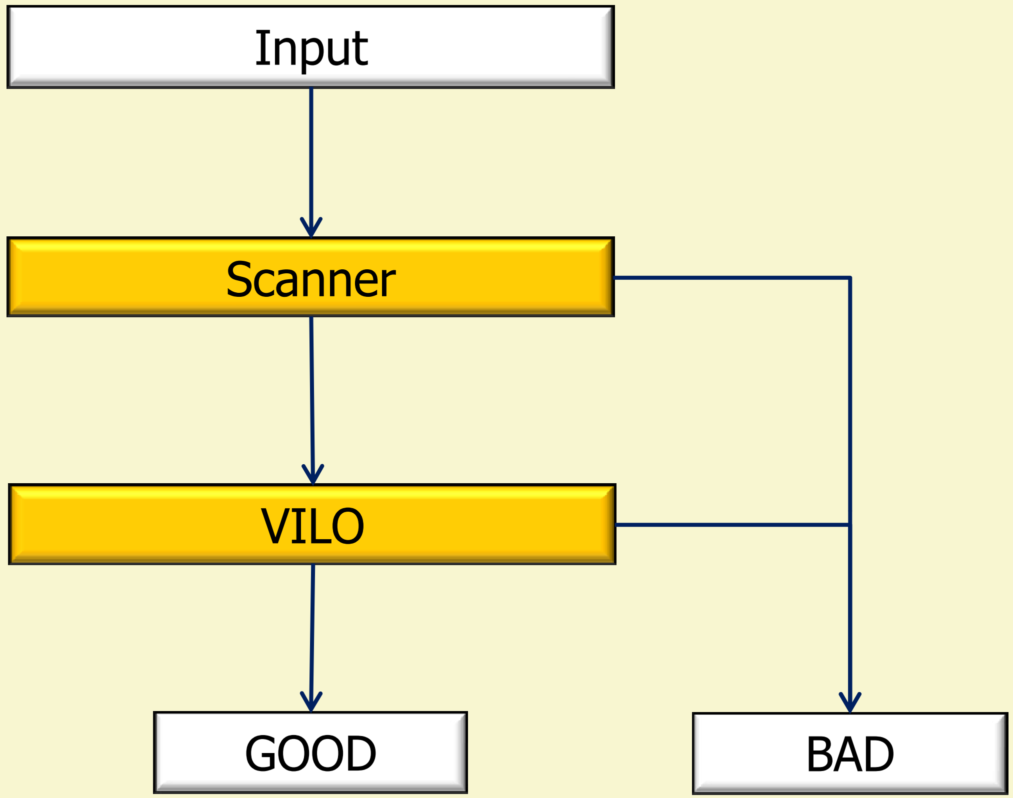
Composition Experiences

- Choices reflect composition ideas in AV
  - Which choices do we use?
- We were experimenting with composition
  - We were building tools for analysis and detection
  - Could compose and integrate in variety of ways
- Ran into some interesting questions along the way…

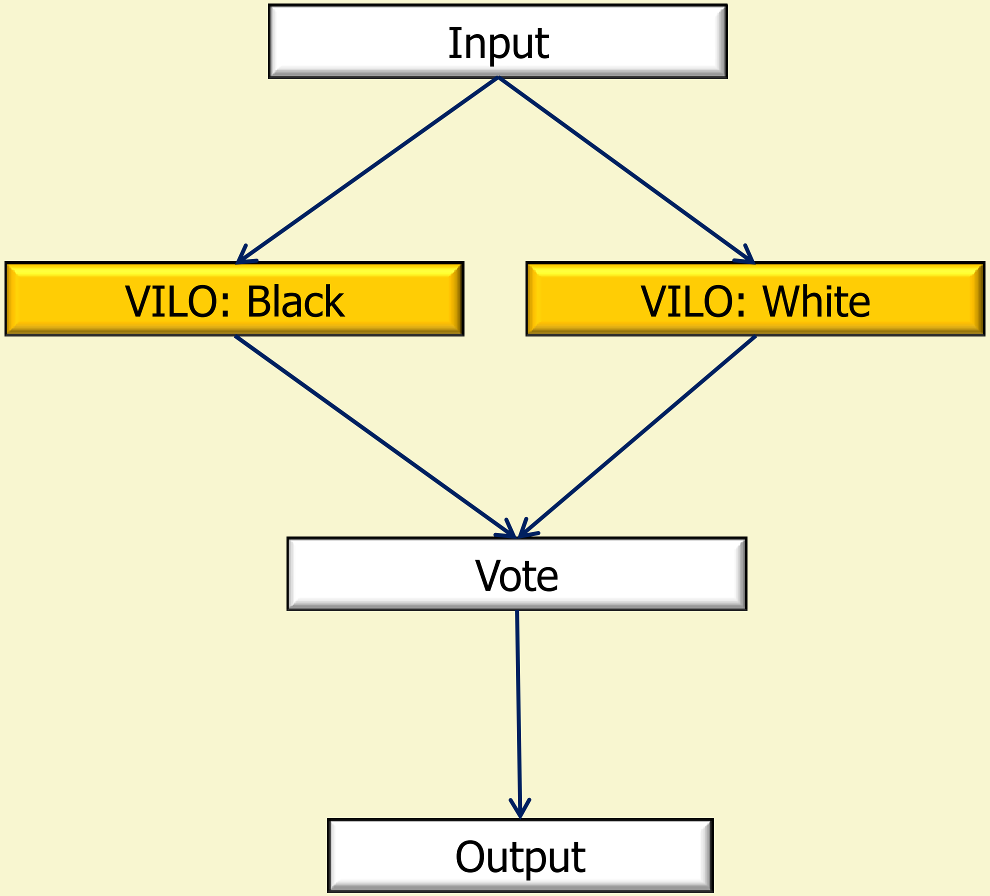
Vilo Composition

- Vilo:
  - Automated classifier / detector
    - Analyzes binaries
    - Constructs generic matcher
  - Applications
    - Black list: use malware for training
    - White list: use benign for training
- Question:
  - How to integrate Vilo into AV systems?

Composition: Vilo in Sequence



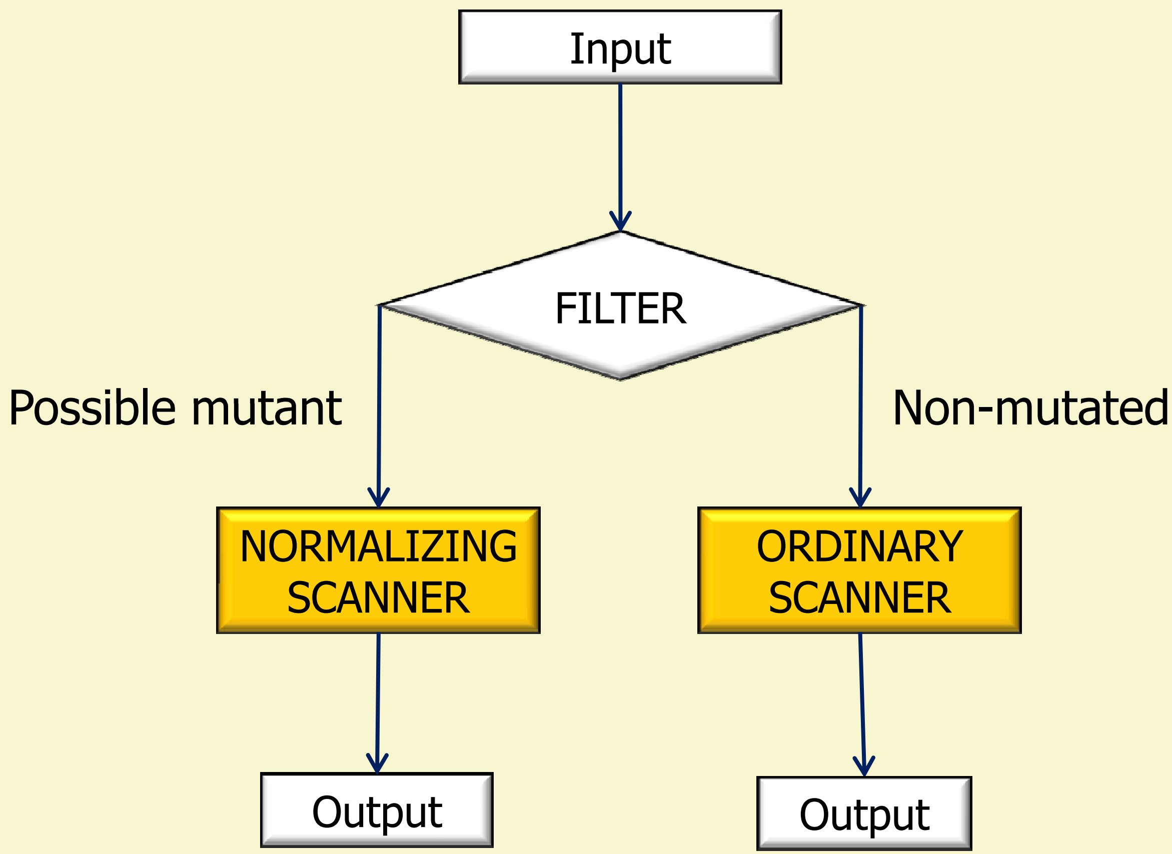
Composition: Vilo in Parallel



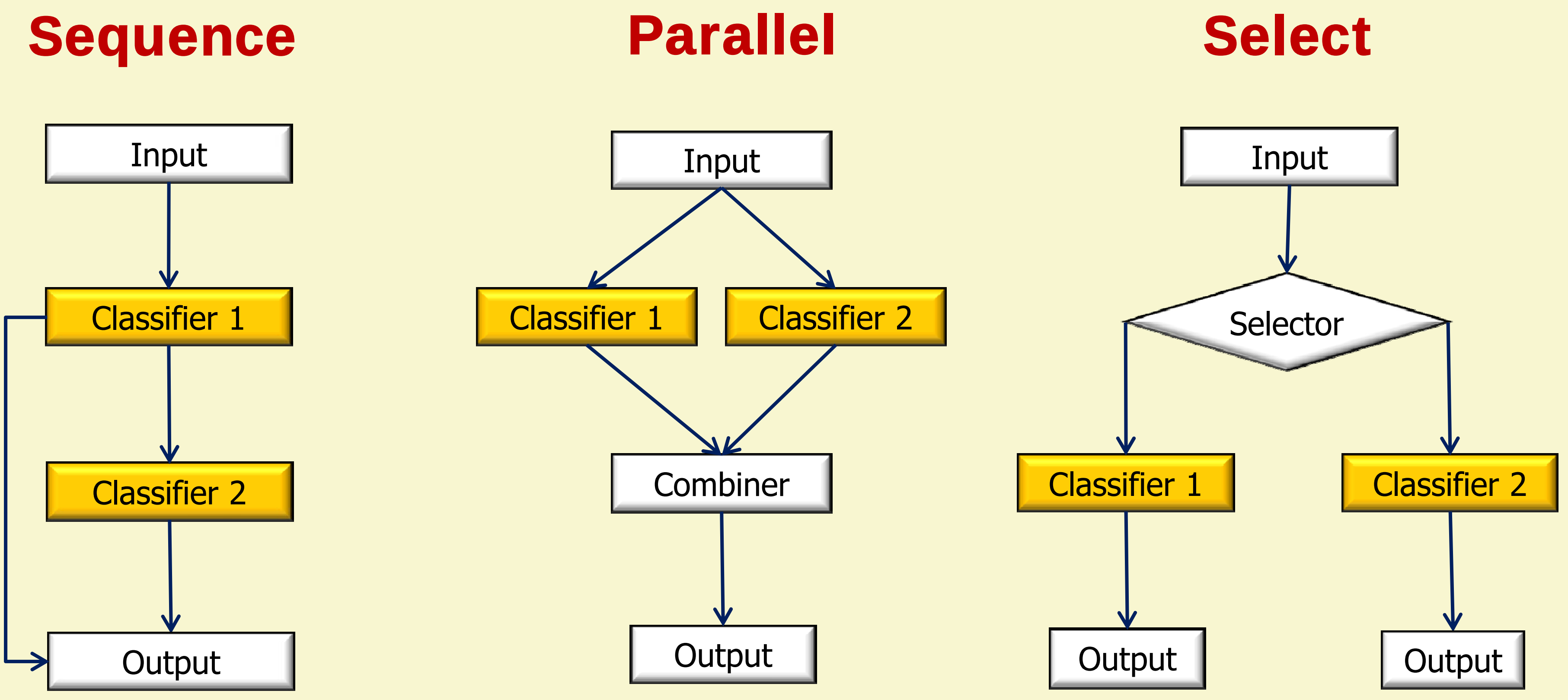
Normalizer/Filter Composition

- Mutant Normalizer:
  - Converts mutants/variants to a single form
  - Perform ordinary scan on normalized form
  - Concern:
    - Relatively expensive
  - Solution:
    - Apply only on files likely to be mutants
    - We developed fast filter to identify likely mutants
- Question:
  - How to integrate Normalizer/Filter into AV system?

Composition: Filter/Normalizer



Composition Choices



Composition: a Way of Life

- Multiple identification methods in AV scanners
  - Crypto checksum
  - X-ray scanning
  - Static behaviour-based patterns
  - Emulation-based behavior matching
  - Heuristic analysis

  …
- Common to be combined in AV system
  – Including composition using selection logic

Important Questions

- Compositions raise important questions
  - How do we know a composition is any good?
  - How do we tune the composed system for optimal performance?
  - If two classifiers are optimally tuned, will their composition also be optimal?
- Game theory can yield insight into such composition problems

Some Interesting Results

- For a particular selector/classifier architecture it can be shown that:
  - Adding another classifier to a scanner will not always make a scanner better
    - better *only if* the cost of "stealthing" the selector is above a specific threshold
  - AV designer is always advised to deter "stealthing" the selector
    - by increasing the spread in the detection rates of the classifiers

Steps To Enlightenment

- Introduce general game theory approach
- Show application to two common architectures
- Derive analysis of game strategies

Game Theory: General Approach

- Game Theory:
  - Aid to analyze strategic choices of adversaries
- Basic idea:
  - Model adversary interaction as game
  - Associate payoffs (costs/benefits) to outcome
  - Mathematical manipulation to analyze strategies
    - Search for optimal strategies

Game Theory Modeling Process

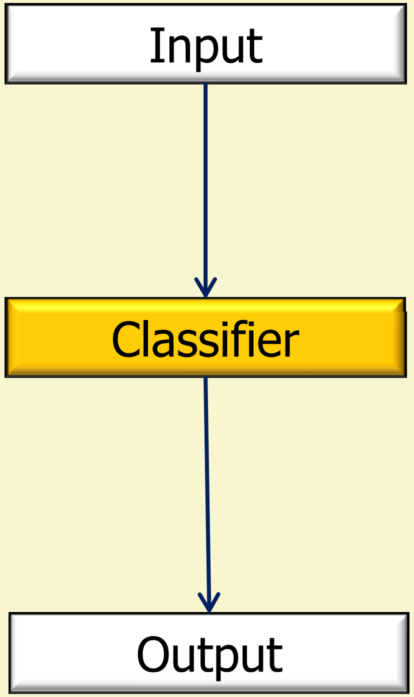
- Four steps
  1. Identify agents
  2. Identify game parameters
  3. Develop game tree
  4. Analyze tree to compute expected payoffs

- Two step introduction using two games:
  - Simple: One classifier
  - Complex: Selector/Classifier

Step 1: Agents & Roles

- Normal User (NU)
  - Presents uninfected files to the system
  - Wants to use system to derive positive utility
- Malware Author (MA)
  - Presents infected files to system
  - Wants to attack system to derive positive utility
- Security Analyst (SA)
  - Attempts to provide optimal system, including:
    - Detect and thwart MA's malware
    - Minimize AV system's total cost

Step 1: Game



- Simple game setup
  - Single classifier

Step 2: Classifier Parameter

- Many classifiers have a tunable parameter
  - Parameter trades off between
    - P_D: true positive rate
    - P_F: false positive rate
  - ROC curve shows relation between P_D and P_F

ROC Curve

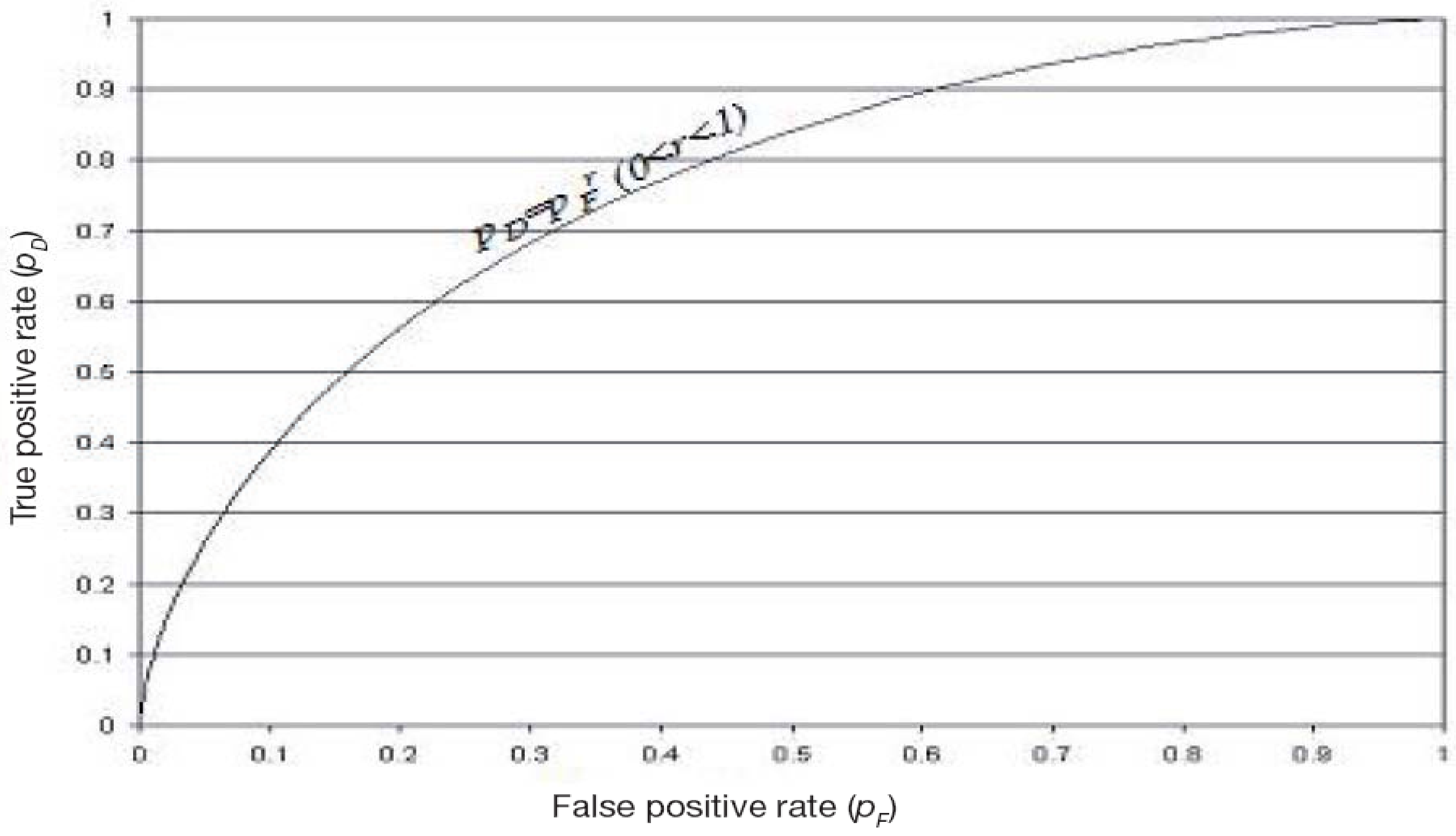


Figure 2: A ROC curve

Step 2: Classifier Parameter

- Parameters are settings the SA can control
  - These define the SA's moves in the game
  - Need to choose parameter to model ROC
- Typical ROC curves follow power function
    - $P_D = P_F^{\,r}$, $0 < r < 1$
  - *r* can be used as model parameter
    - i.e., SA chooses *r* as part of the game strategy

Step 2: Outcomes and Payoffs

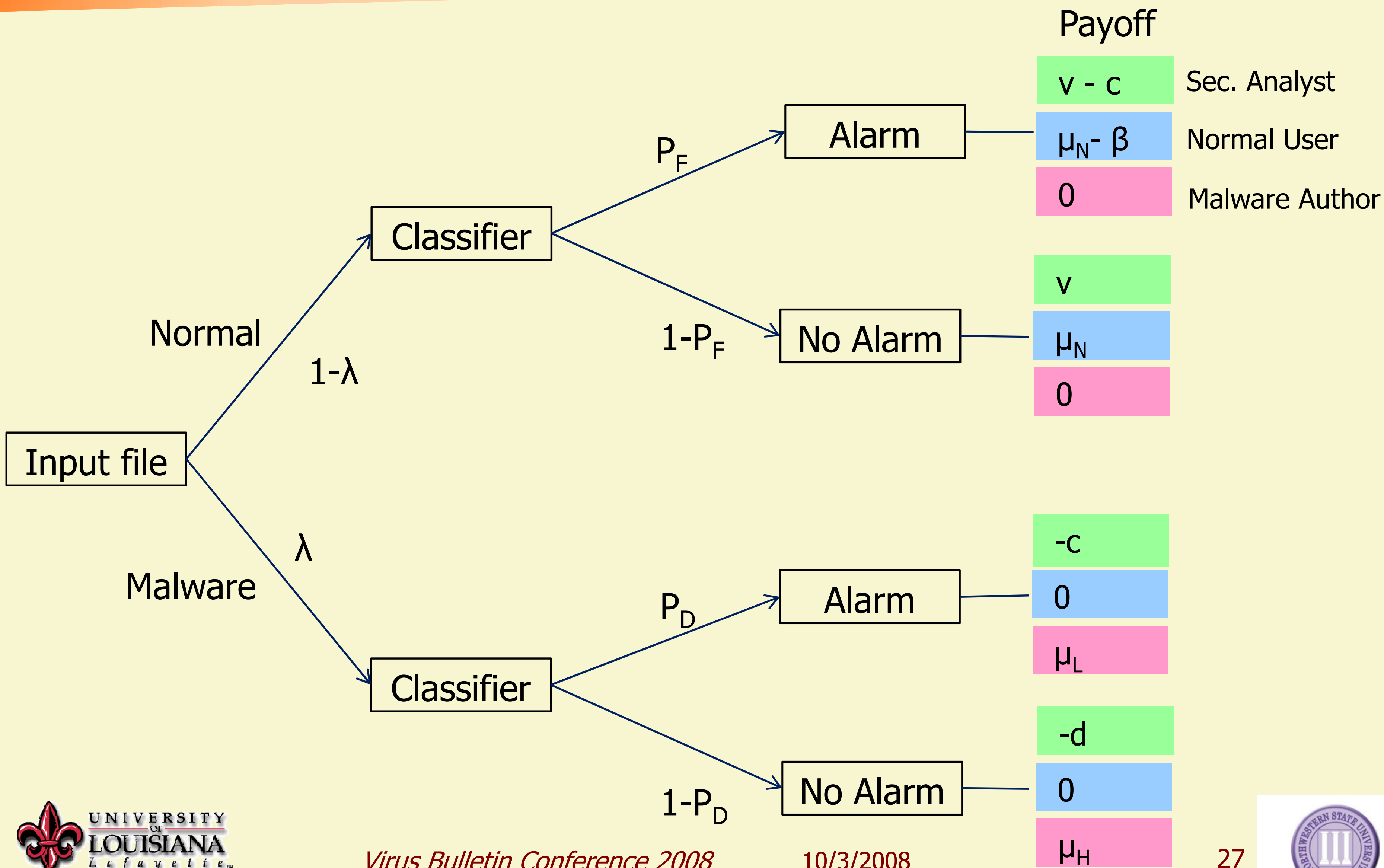
- Actual payoffs for agents are their *benefits less costs* given a particular game outcome
- Define the game based on analysis of SA, MA, and NU payoffs

Step 2: Outcomes and Payoffs

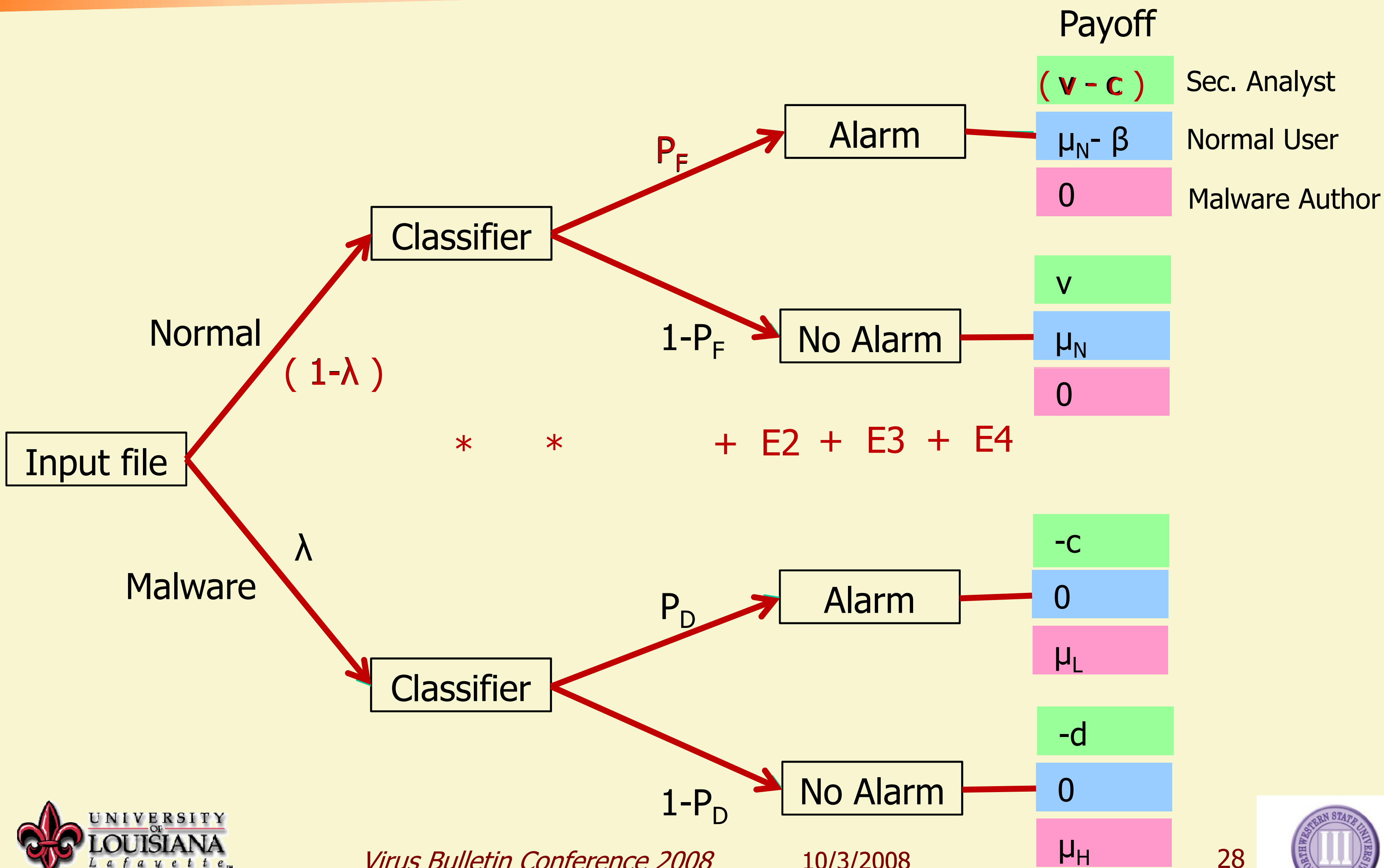
Outcomes		Benefits SA	Benefits NU	Benefits MA	Costs SA	Costs NU	Costs MA
Normal	Alarm	v	μ_N		c	β	
	No Alarm	v	μ_N				
Malware	Alarm			μ_L	c		
	No Alarm			μ_H	d		

MA damages SA if malware gets through

Step 3: Construct Game Tree



Step 4: Expected Payoff Analysis



Step 4: Expected Payoff Analysis

- The expected payoffs for all agents:

  NU: $(\mu_N - \beta)p_F + \mu_N(1-p_F) = \mu_N - \beta p_F$

  MA: $\mu_H(1-p_D) + \mu_L p_D$

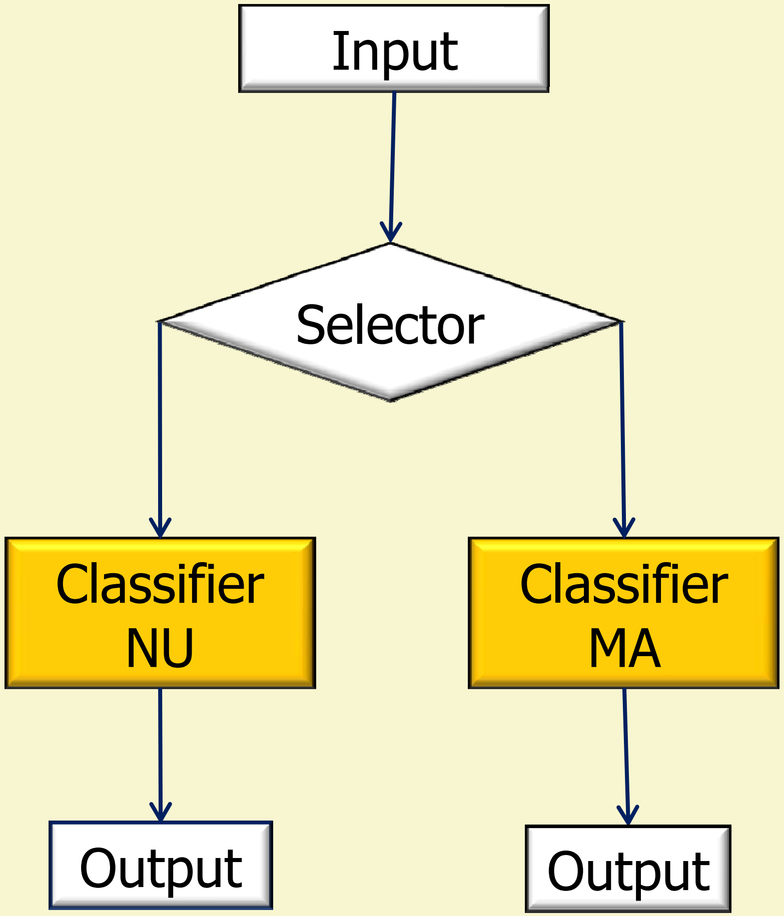
  SA: $v - (d+v)\lambda - c(1-\lambda)p_F + (d-c)\lambda p_D$

Step 4: Strategy Analysis

- Optimal solution for SA:

$$p_D = \left(\frac{\xi}{r}\right)^{\frac{r}{r-1}} \text{ where } \xi = \frac{c}{d-c} \times \frac{1-\lambda}{\lambda}$$

Selector Game



- SA
  - Sets up system
  - Tunes it
- MA
  - Chooses anti-AV technique
  - Sends cloaked file
- Question:
  - Optimal parameters?

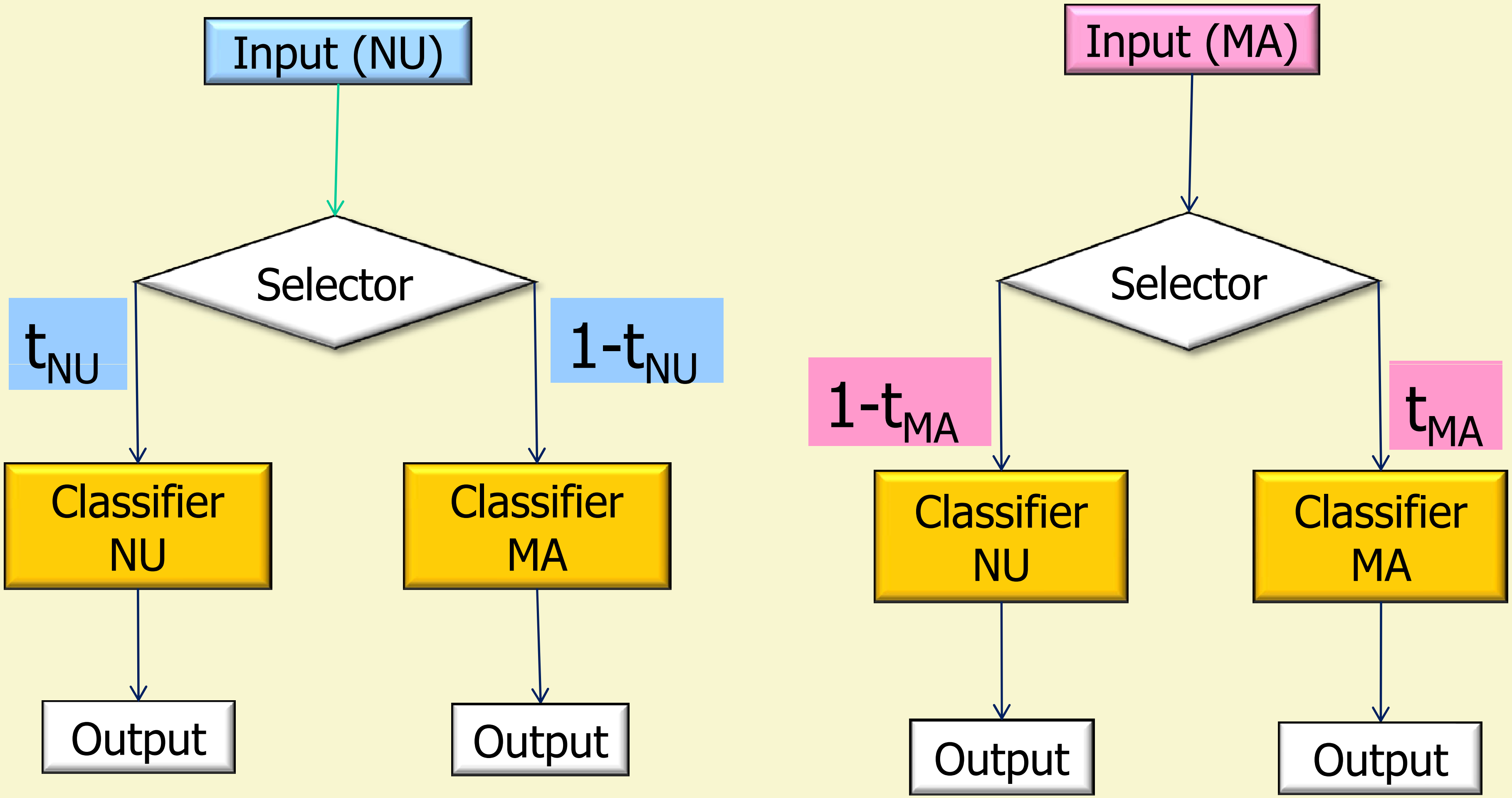
Game Theory Steps - Revisited

- Four steps
  1. Identify agents
  2. Identify game parameters
  3. Develop game tree
  4. Analyze tree to compute expected payoffs

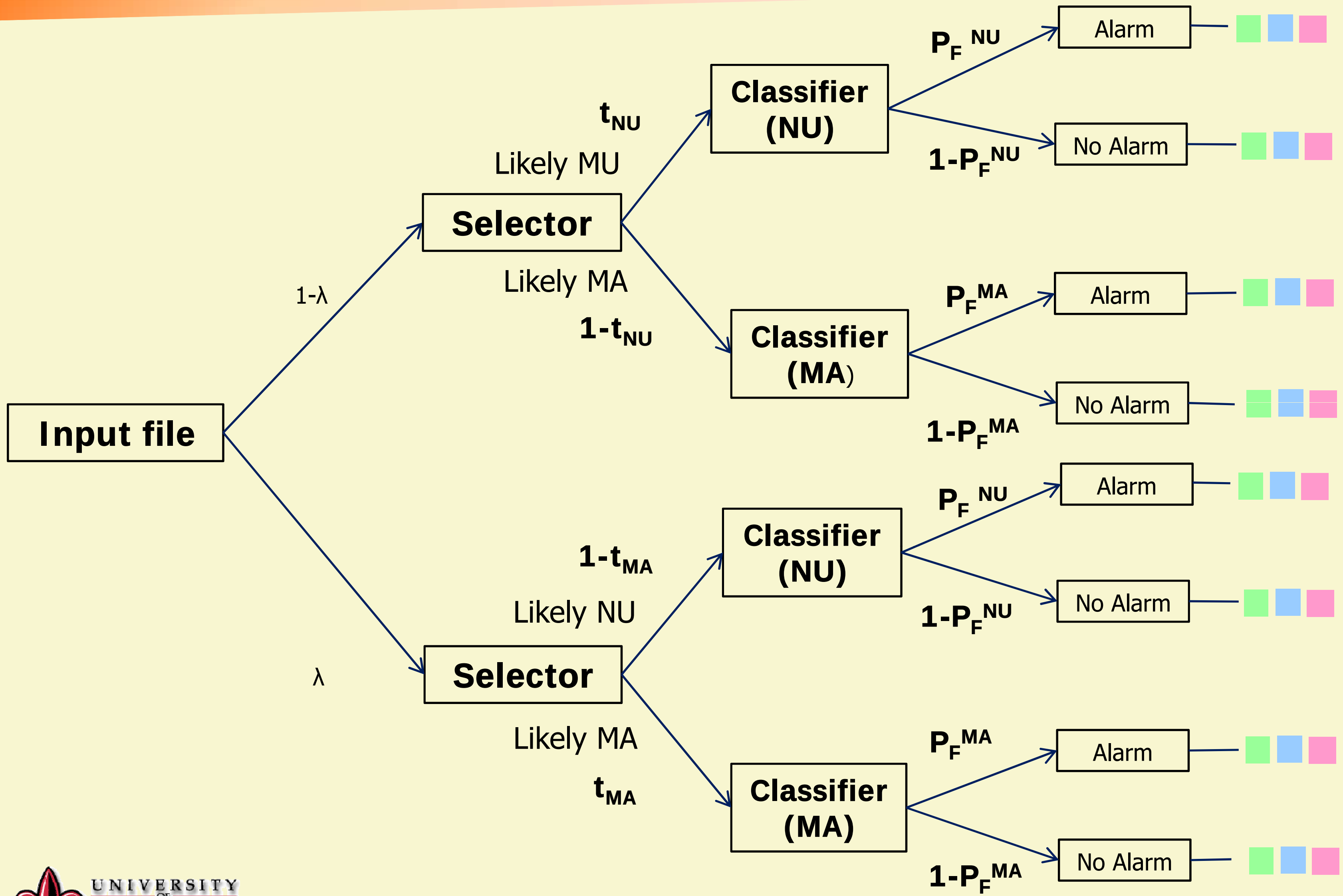
Step 2: Outcomes and Payoffs (Δ)

Outcomes		Benefits			A	Costs		
		SA	NU	MA		SA	NU	MA
Normal	Alarm	v	μ_N			c	β	
	No Alarm	v	μ_N					
Malware (normal)	Alarm			μ_L		c		
	No Alarm			μ_H		d		
Malware (stealth)	Alarm			μ_L		c		Δ
	No Alarm			μ_H		d		Δ

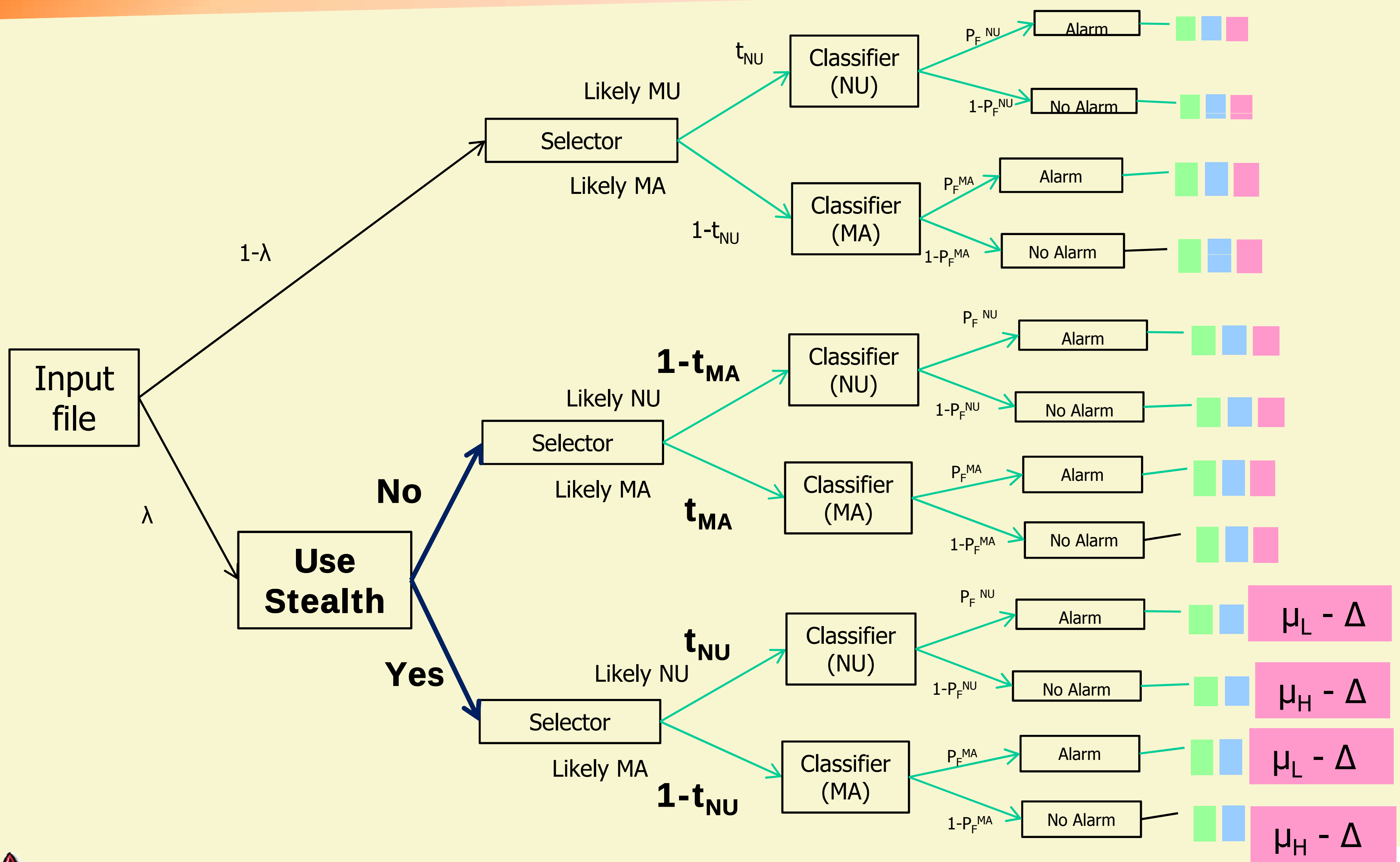
Step 2: Parameters (t_{NU} and t_{MA})



Step 3: Game Tree (no Stealth)



Step 3: Game Tree (w/ Stealth)



Step 4: Strategy Analysis

- Game tree analysis yields expected payoffs

NU: $t_{NU}((\mu_N-\beta)p_F^{NU}+\mu_N(1-p_F^{NU}))+(1-t_{NU})(p_F^{MA}(\mu_N-\beta)+(1-p_F^{MA})\mu_N)$

MA if not using anti-AV:

$(1-t_{MA})(\mu_l p_D^{NU}+\mu_h(1-p_D^{NU}))+t_{MA}(\mu_l p_D^{MA}+\mu_h(1-p_D^{MA}))$

MA if using anti-AV:

$(1-t_{NU})((\mu_l-\Delta)p_D^{MA}+(\mu_h-\Delta)(1-p_D^{MA}))+t_{NU}((\mu_l-\Delta)p_D^{NU}+(\mu_h-\Delta)(1-p_D^{NU}))$

SA: *p(selected as normal, alarm) * [p(normal file | selected as normal, alarm)*v – c] + p(selected as normal, no alarm) * [p(normal file | selected as normal, no alarm)*v – p(malware | selected as normal, no alarm)*d] + p(selected as malware, alarm) * [p(normal file | selected as malware, alarm)*v – c] + p(selected as malware, no alarm) * [p(normal file | selected as malware, no alarm)*v – p(malware | selected as malware, no alarm)*d]*[1]

Step 4: Optimal Solutions

- Optimal solution for SA:

  If $\Delta \geq$ Threshold(r) then $p_D^{MA} = f(r)$ and $p_D^{NU} = g(r)$

  If $\Delta <$ Threshold(r) then $p_D^{MA} - p_D^{NU} = \dfrac{\Delta}{(\mu_H - \mu_L)(t_{MA} + t_{NU} - 1)}$

  and $(1 - t_{NU})(p_D^{MA})^{\frac{1-r}{r}} + t_{NU}(p_D^{NU})^{\frac{1-r}{r}} = \dfrac{r}{\xi}$

Where

$$Threshold(r) = (t_{MA} + t_{NU} - 1)(f(r) - g(r))(\mu_H - \mu_L)$$

$$f(r) = \left(\frac{\xi}{r} \times \frac{1 - t_{NU}}{t_{MA}}\right)^{\frac{r}{r-1}} \text{ and } g(r) = \left(\frac{\xi}{r} \times \frac{t_{MA}}{1 - t_{MA}}\right)^{\frac{r}{r-1}}$$

Step 4: Insights

- For a particular selector/classifier architecture it can be shown that:
  - Adding another classifier to a scanner will not always make a scanner better
    - better *only if* the cost of "stealthing" the selector is above a specific threshold
  - AV designer is always advised to deter "stealthing" the selector
    - by increasing the spread in the detection rates of the classifiers
- Have equations for setting parameters

Conclusions

- Introduced way to analyse AV systems using Game Theory
- Showed it may lead to interesting, possibly counter-intuitive results
- Mathematically derive optimal configurations

Thanks!