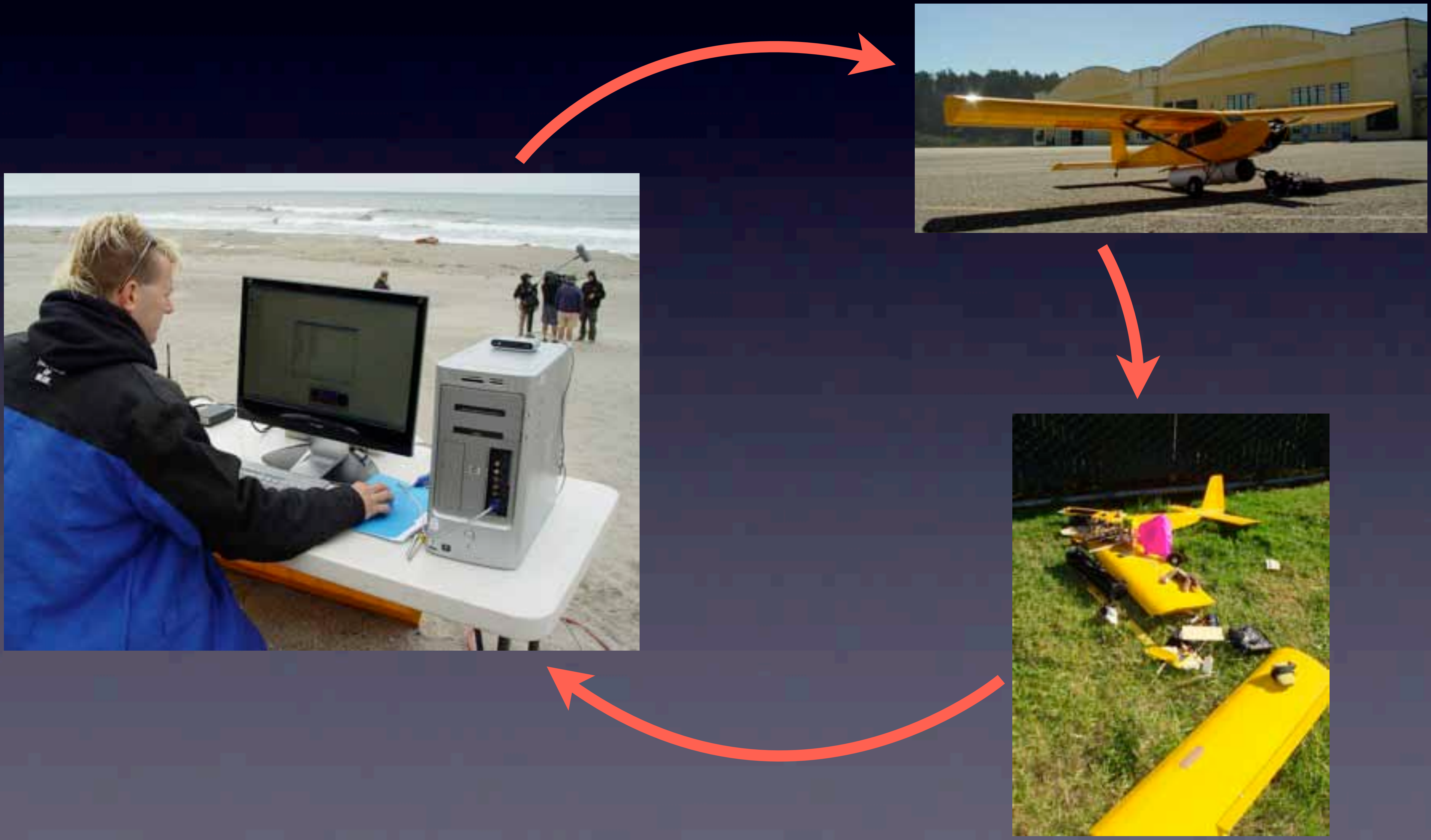
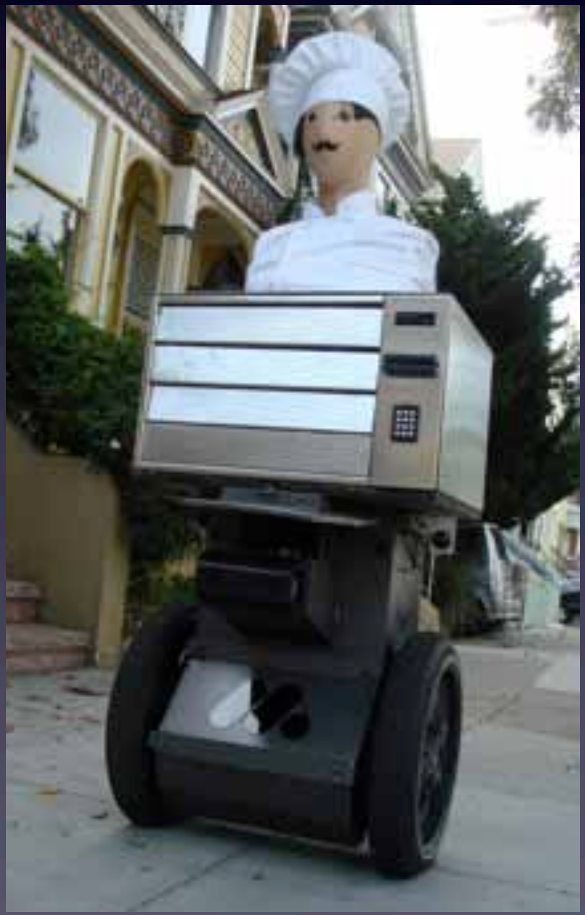
Hacking Driverless Vehicles

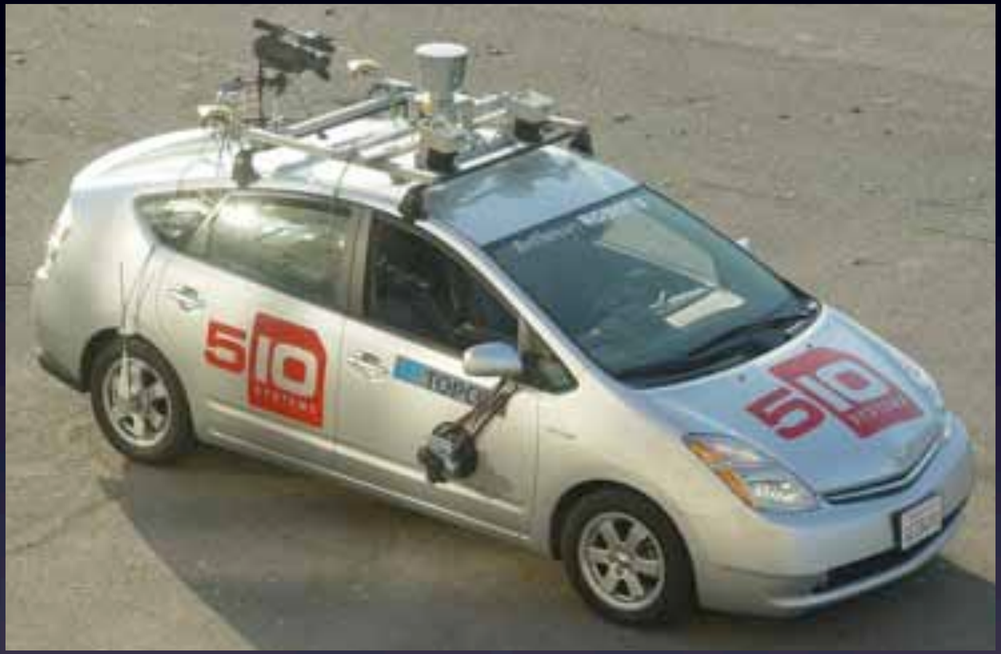
Zoz

PROTOTYPE
THIS



PROTOTYPE
THIS




510
SYSTEMS

robonation
ROBOTICS COMMUNITY

Intelligent Ground Vehicle Competition

Student Unmanned Aerial Systems

RoboBoat

RoboSub

International Aerial Robotics Competition

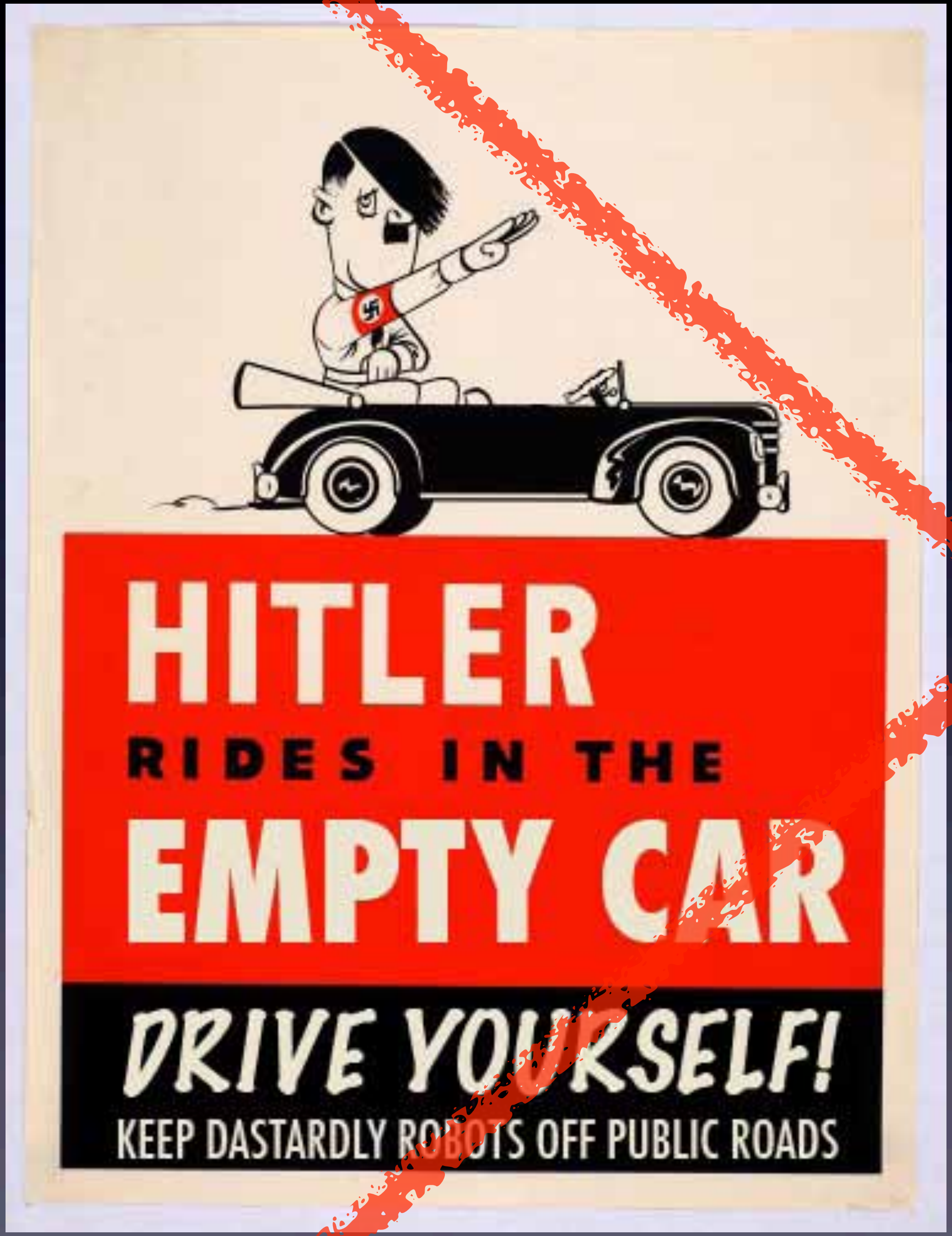
AUVSIfoundation
ASSOCIATION FOR UNMANNED VEHICLE SYSTEMS INTERNATIONAL

The Revolution Is Coming

- Advantages:
  - Energy efficiency
  - Time efficiency
  - New applications

The Revolution Is Coming

~~FUD~~


HITLER
RIDES IN THE
EMPTY CAR
DRIVE YOURSELF!
KEEP DASTARDLY ROBOTS OFF PUBLIC ROADS

When the car drives itself
you ride with Hitler !
Keep
your hands on the
WHEEL!

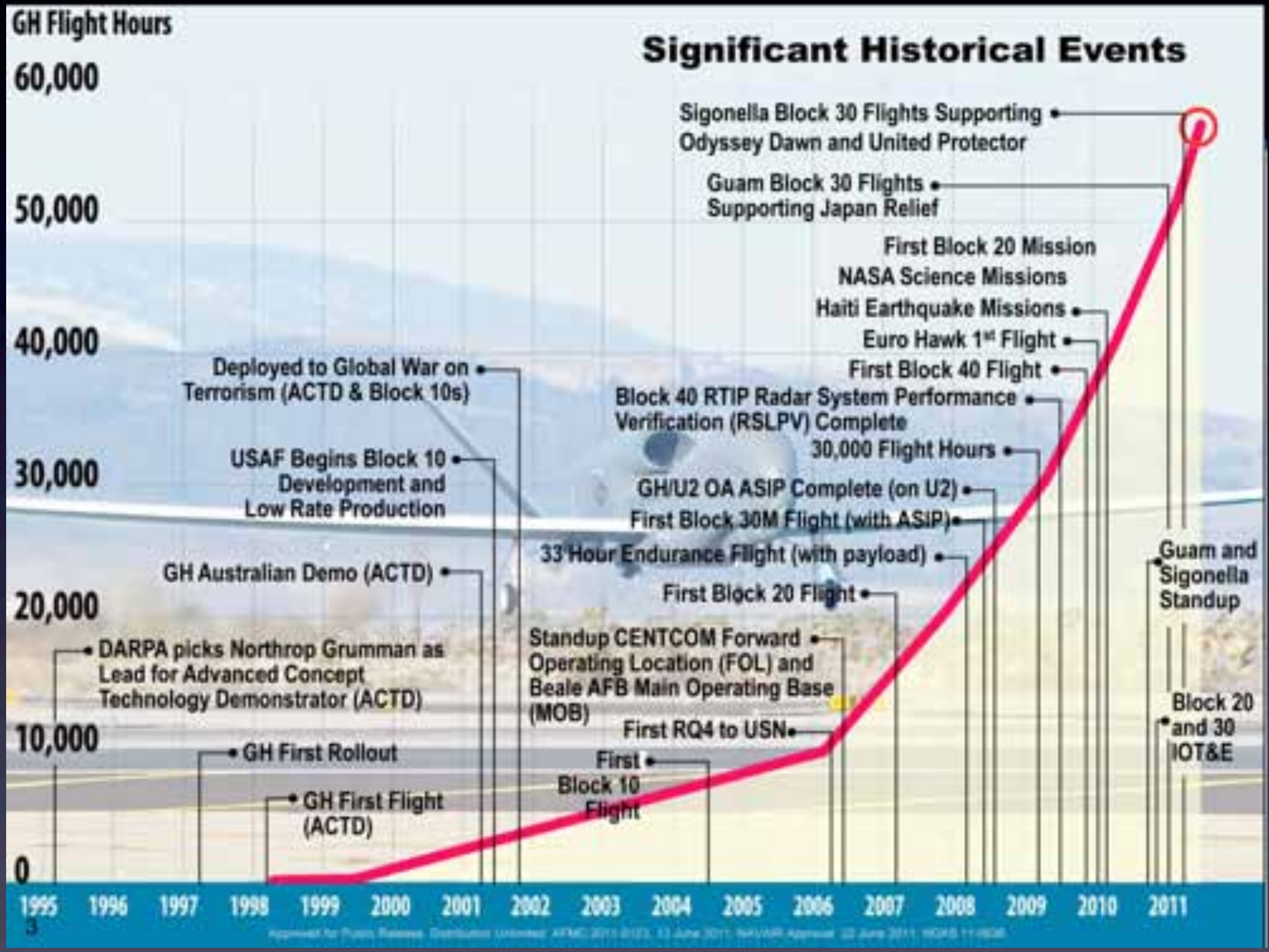
Autonomous/Unmanned Systems

Autonomous/Unmanned Systems

Autonomous/Unmanned Systems

- No human driver/pilot on-board
- May have off-board controller/supervisor
- May have on-board safety pilot/passengers
- Military early adopters

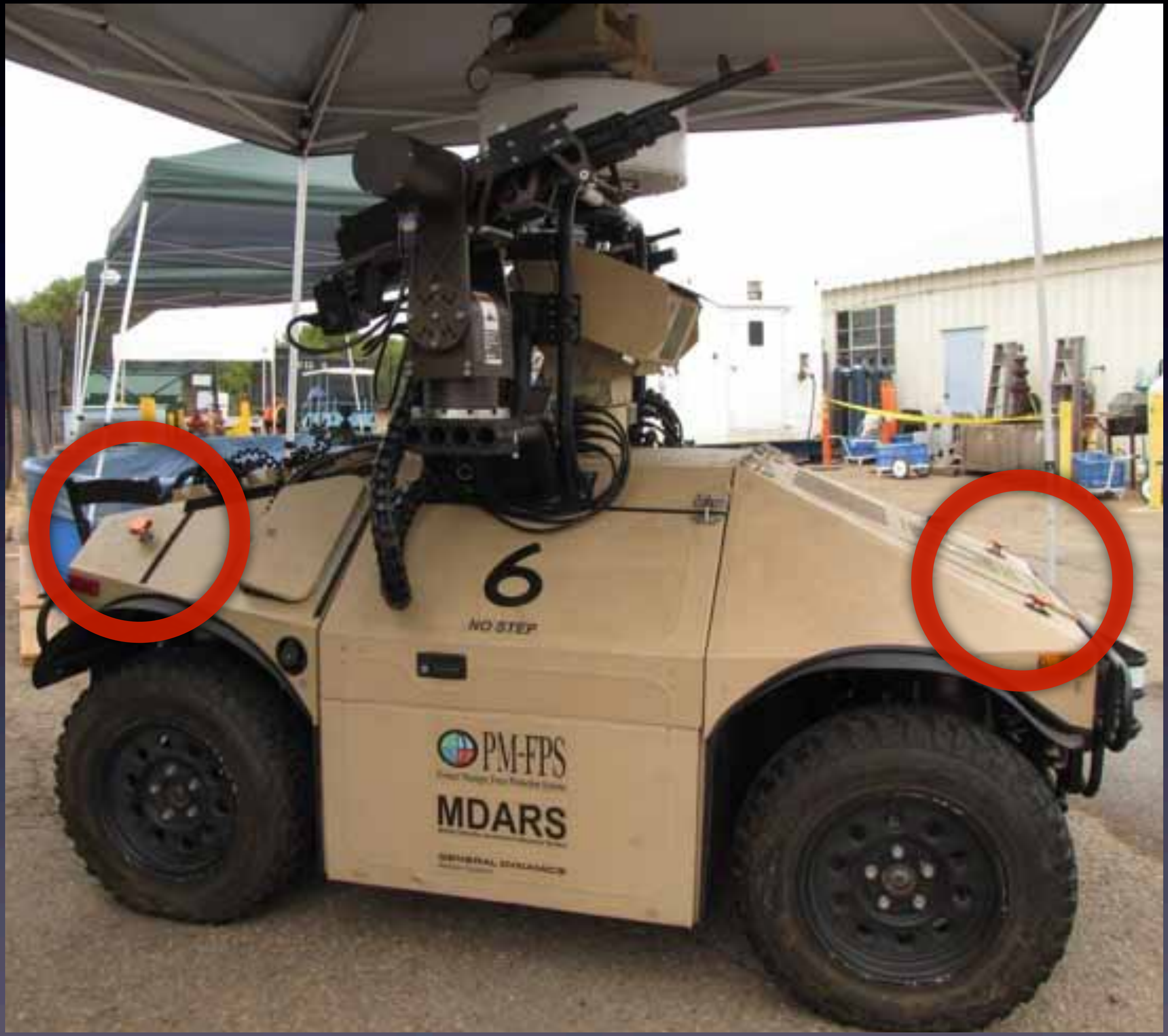
UAS Uptake

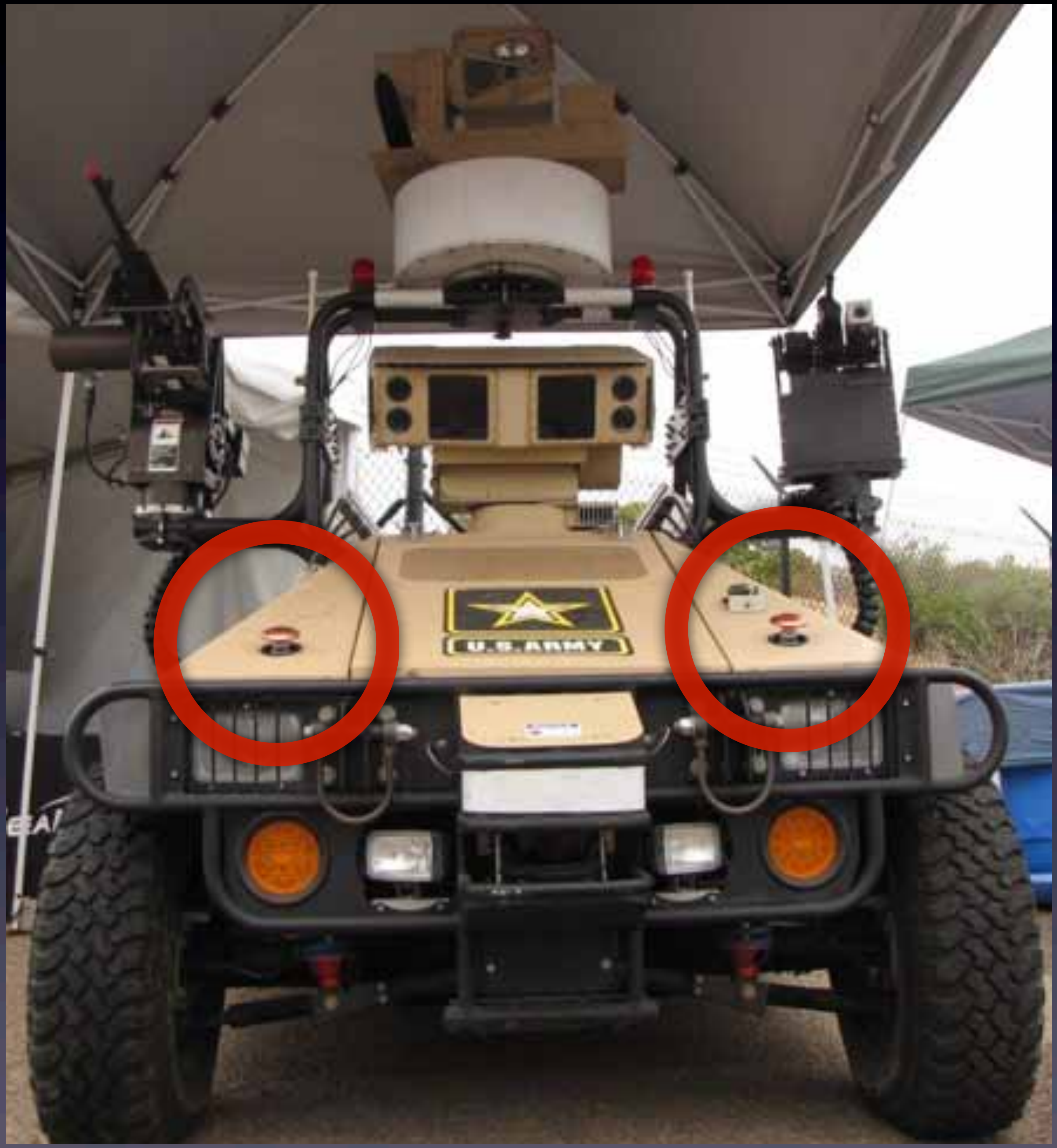


Northrop Grumman

"Unmanned Advanced Capability Aircraft and Ground Combat Vehicles
It shall be a goal of the Armed Forces to achieve the fielding of unmanned, remotely controlled technology such that by 2015, one-third of the operational ground combat vehicles of the Armed Forces are unmanned."
—*National Defense Authorization Act for Fiscal Year 2001* (S. 2549, Sec. 217)

Some UGVs are designed with threats in mind...





Civil Applications

Transportation

Oceanography

Mapping

Filmmaking

Powerline Inspection

Logistics

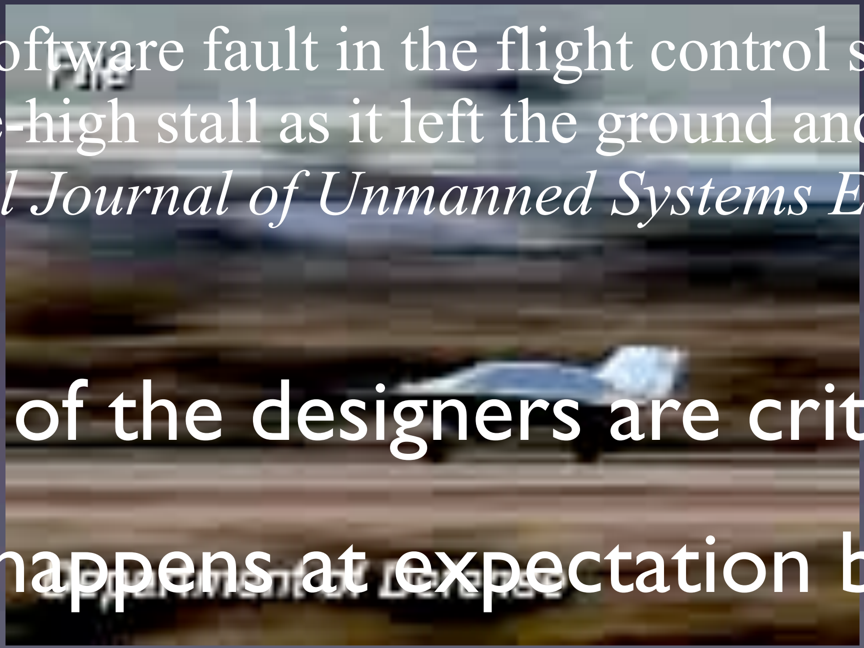
Civil Applications

- Priorities:
  - Precision Agriculture
  - Self-Driving Cars
- Roadblocks:
  - Shared Infrastructure (Airspace, Roads)
  - Acceptance (Safety, Robustness)
- Let's Talk Failure!

Classic Failures

RQ-3 DarkStar

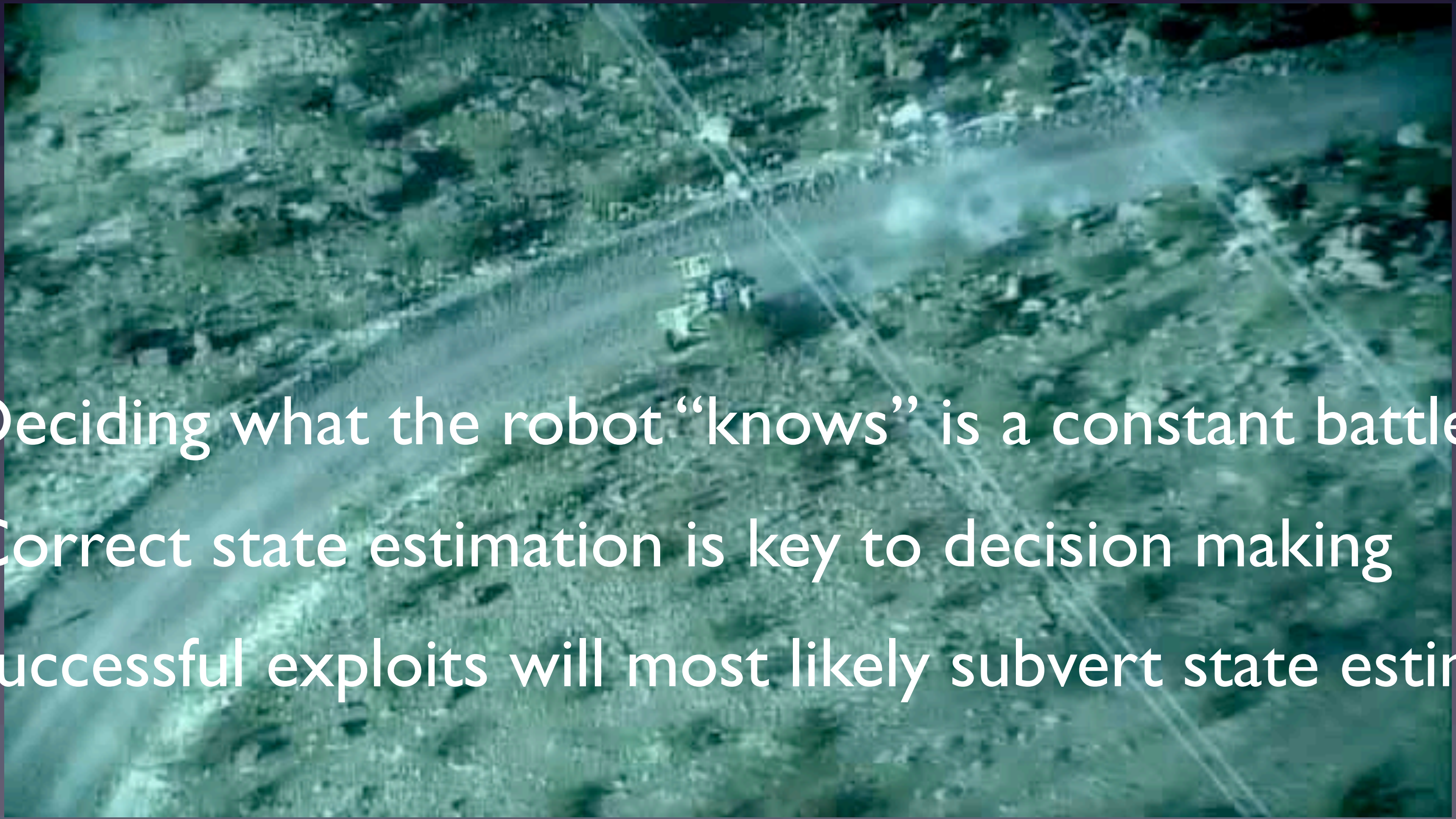
$10m Unit Procurement Cost (Units 11-20, 1994 $)



> On its second flight, due to a software fault in the flight control system the aircraft's porpoising oscillations increased to a nose-high stall as it left the ground and the vehicle crashed.
>
> —*International Journal of Unmanned Systems Engineering, Vol. 1, No. S3, 1–5*

- Expectations of the designers are critical!
- Exploitation happens at expectation boundary “cracks”

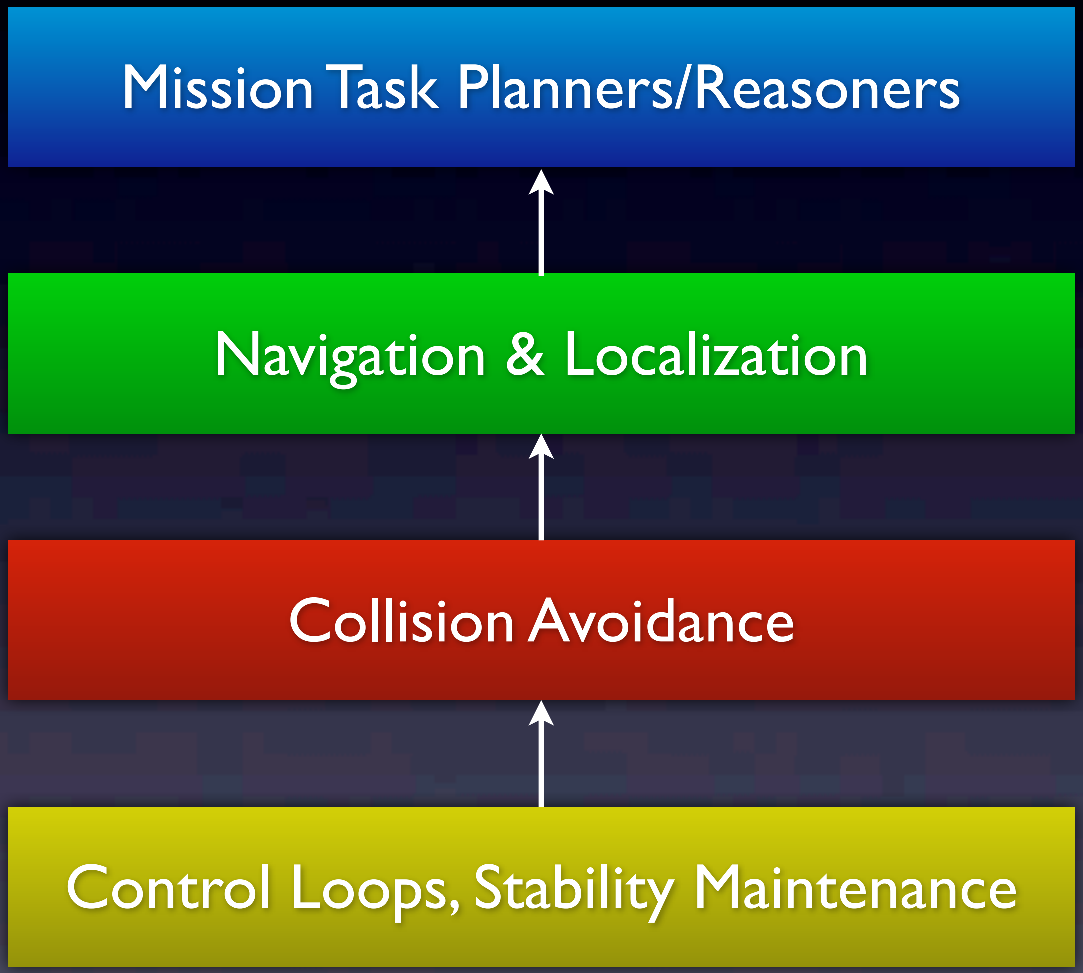
Classic Failures



- Deciding what the robot "knows" is a constant battle
- Correct state estimation is key to decision making
- Successful exploits will most likely subvert state estimation

Autonomous Vehicle Logic Structures

Activity Hierarchy



Mission Task Planners/Reasoners

Navigation & Localization

Collision Avoidance

Control Loops, Stability Maintenance

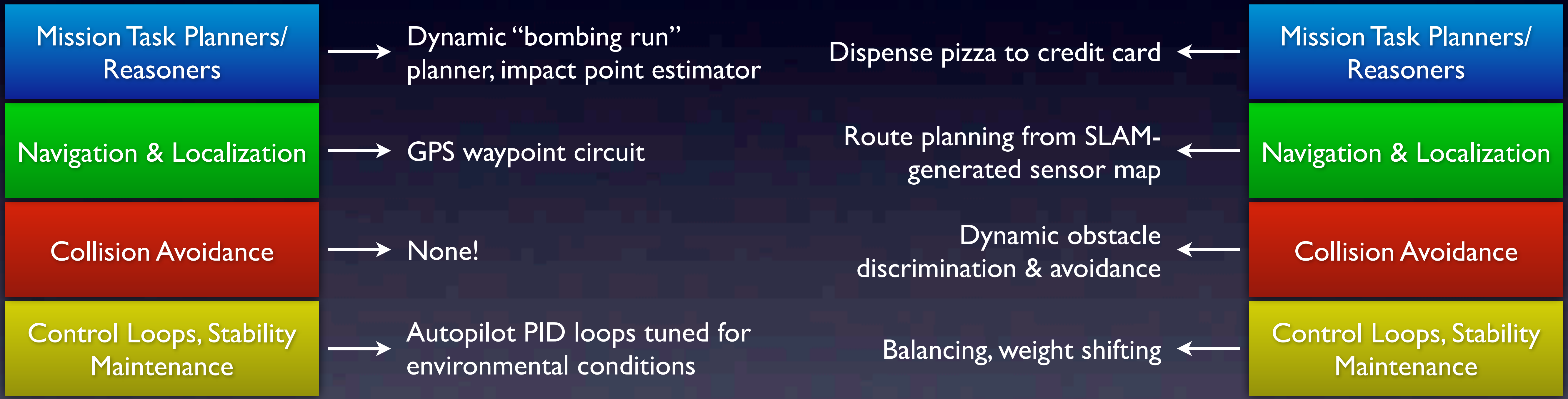
- Attacks lower in the stack defeat everything above
- More engineering effort spent on guaranteed robustness at lower levels
  - Lower layers may be juicier but harder targets

Autonomous Vehicle Logic Structures

Examples

Lifesaving Drone

Pizza Delivery



Mission Task Planners/ Reasoners → Dynamic “bombing run” planner, impact point estimator

Navigation & Localization → GPS waypoint circuit

Collision Avoidance → None!

Control Loops, Stability Maintenance → Autopilot PID loops tuned for environmental conditions

Dispense pizza to credit card ← Mission Task Planners/ Reasoners

Route planning from SLAM-generated sensor map ← Navigation & Localization

Dynamic obstacle discrimination & avoidance ← Collision Avoidance

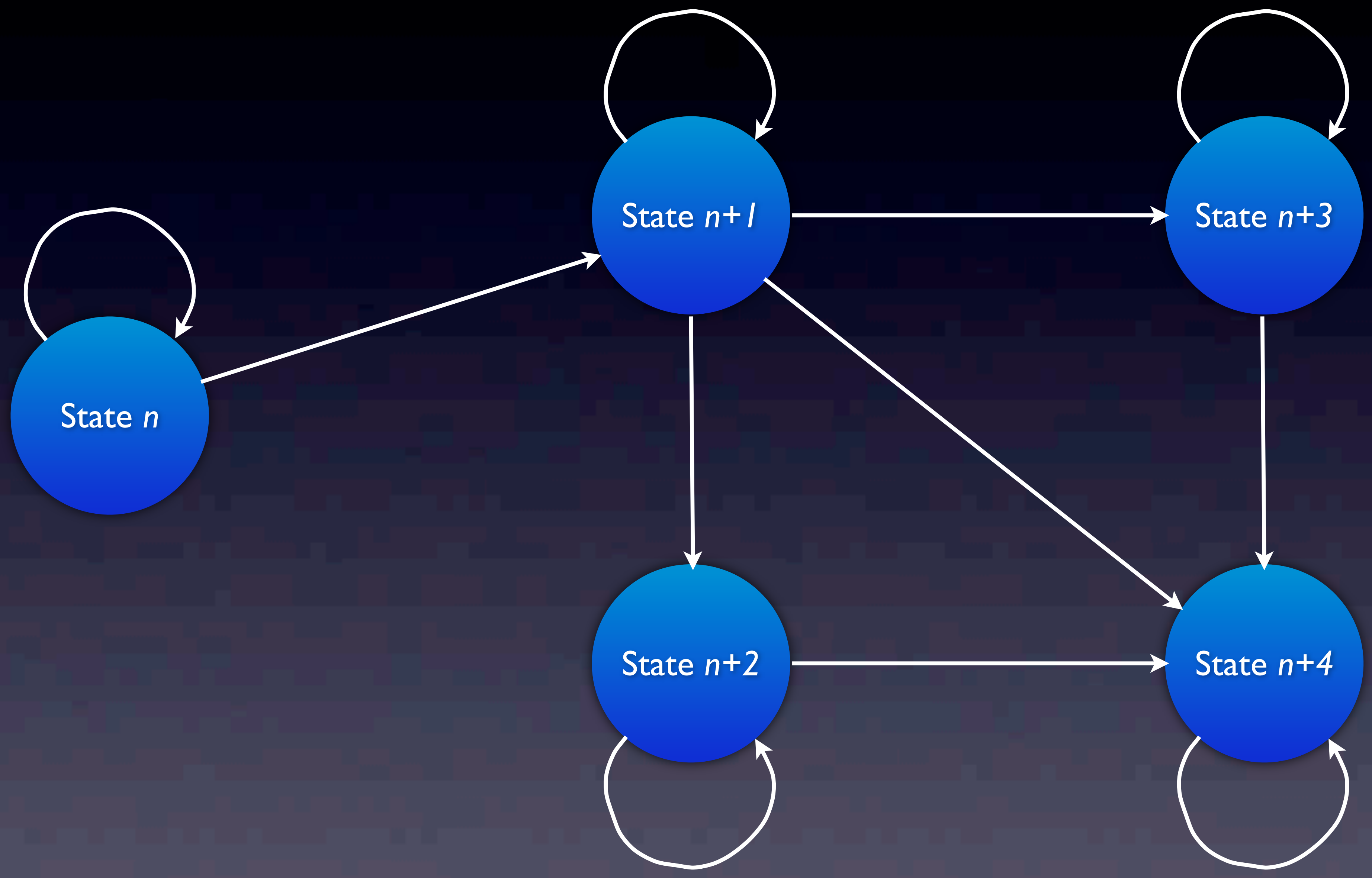
Balancing, weight shifting ← Control Loops, Stability Maintenance

- Extremely vulnerable to collision
- High level logic depends on single sensor

- Vulnerable to redirection, trapping and map-confusion attacks

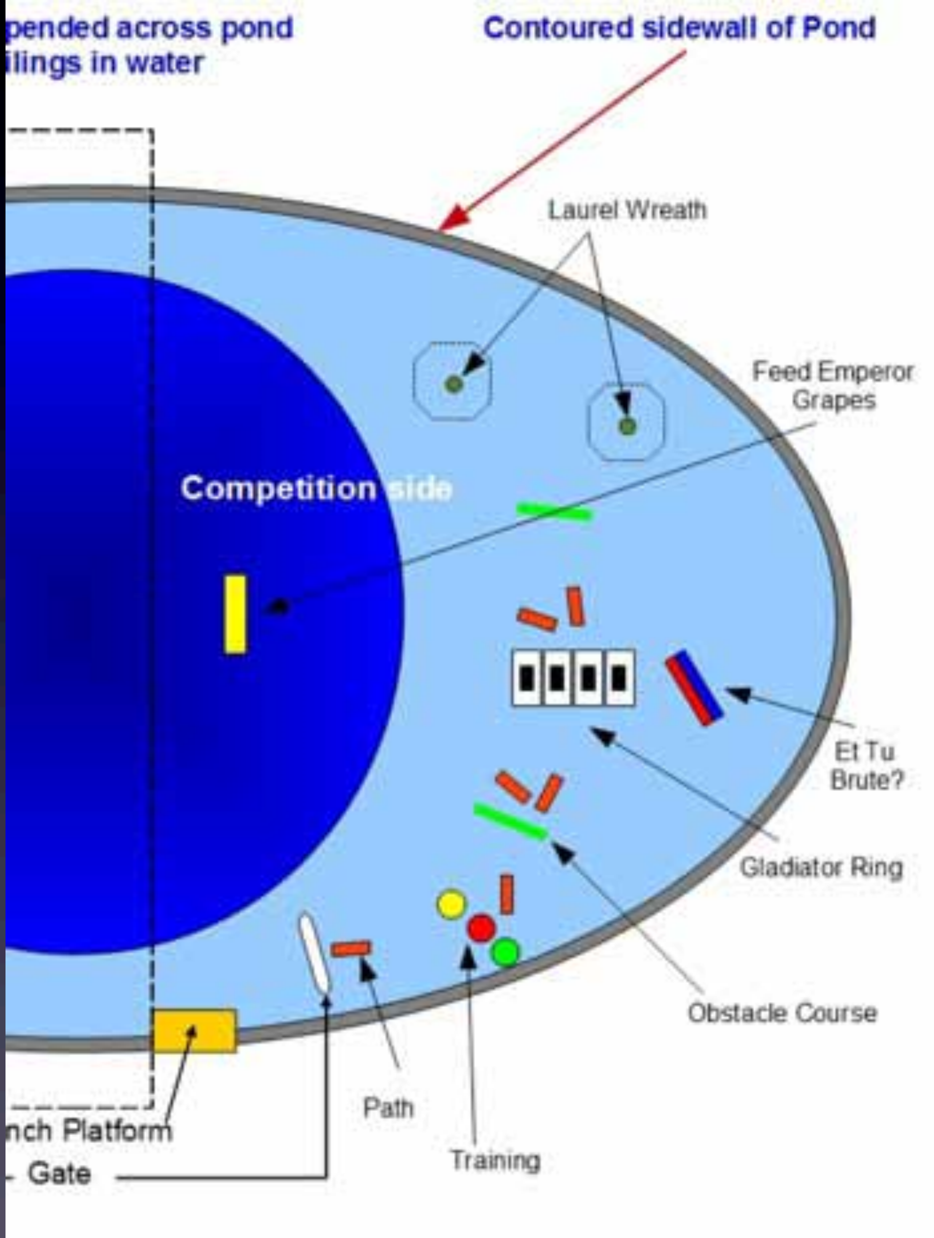
Autonomous Vehicle Logic Structures

Mission Oriented State Machines

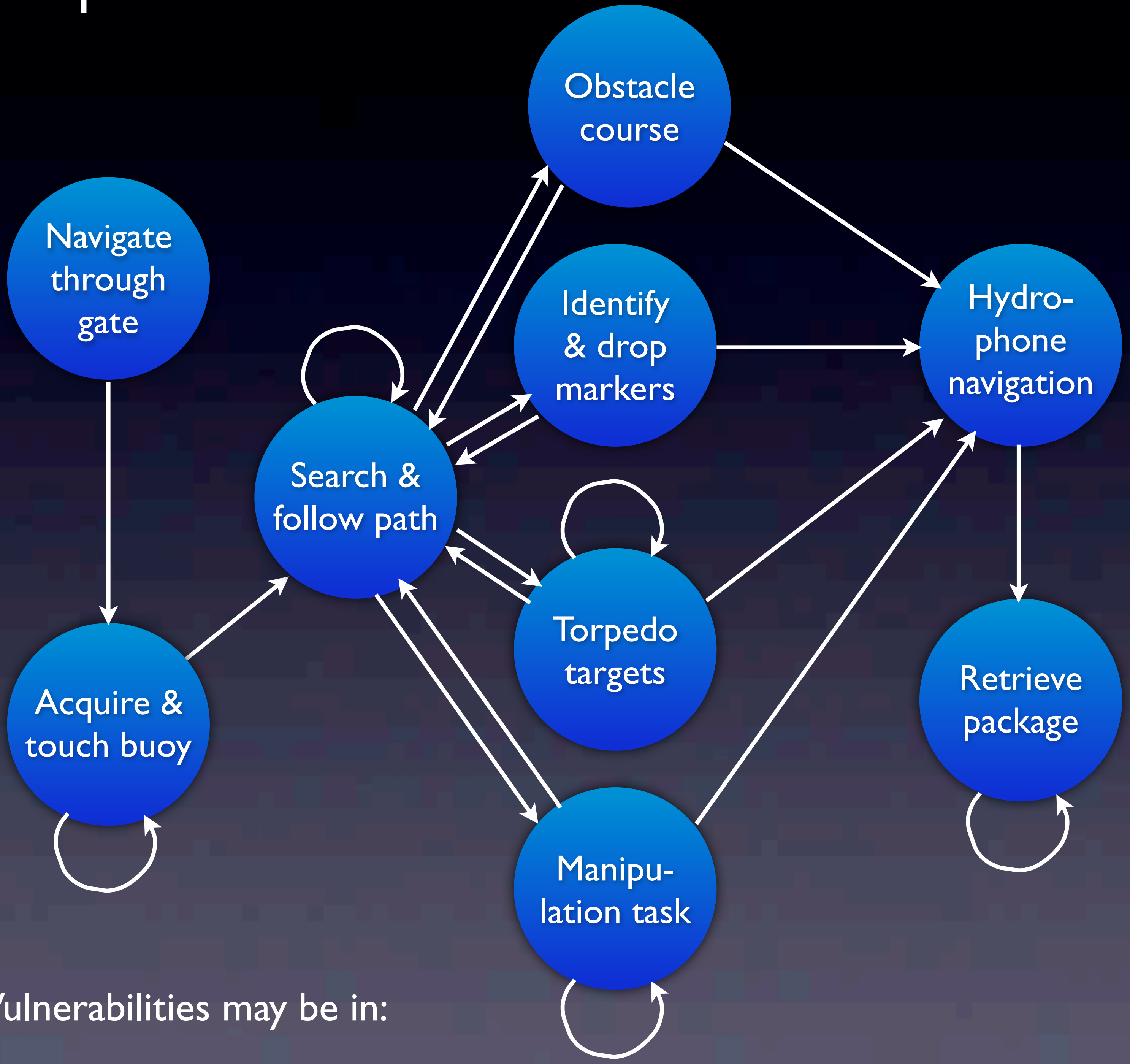


- States may correspond to tasks
- Transitions may be task completions, context switches or timeouts
- States may themselves contain state machines, reasoners, planners etc

Autonomous Vehicle Logic Structures



Example: Robosub Mission


Navigate through gate

Acquire & touch buoy

Search & follow path

Obstacle course

Identify & drop markers

Torpedo targets

Manipulation task

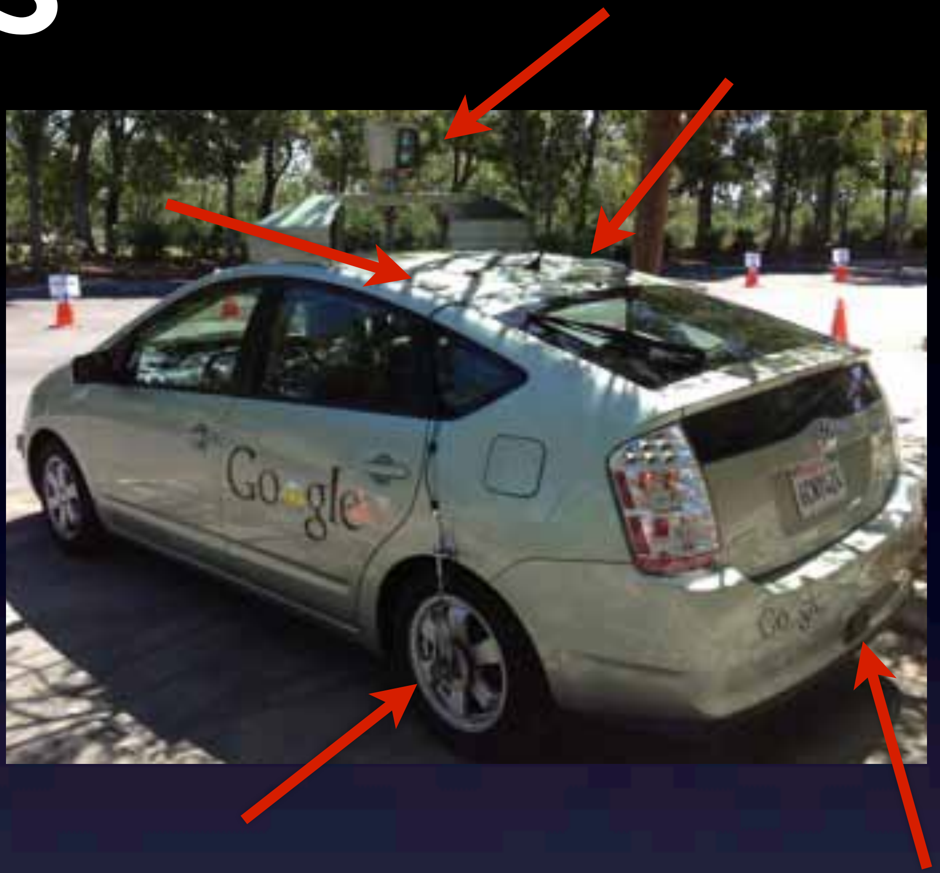
Hydrophone navigation

Retrieve package

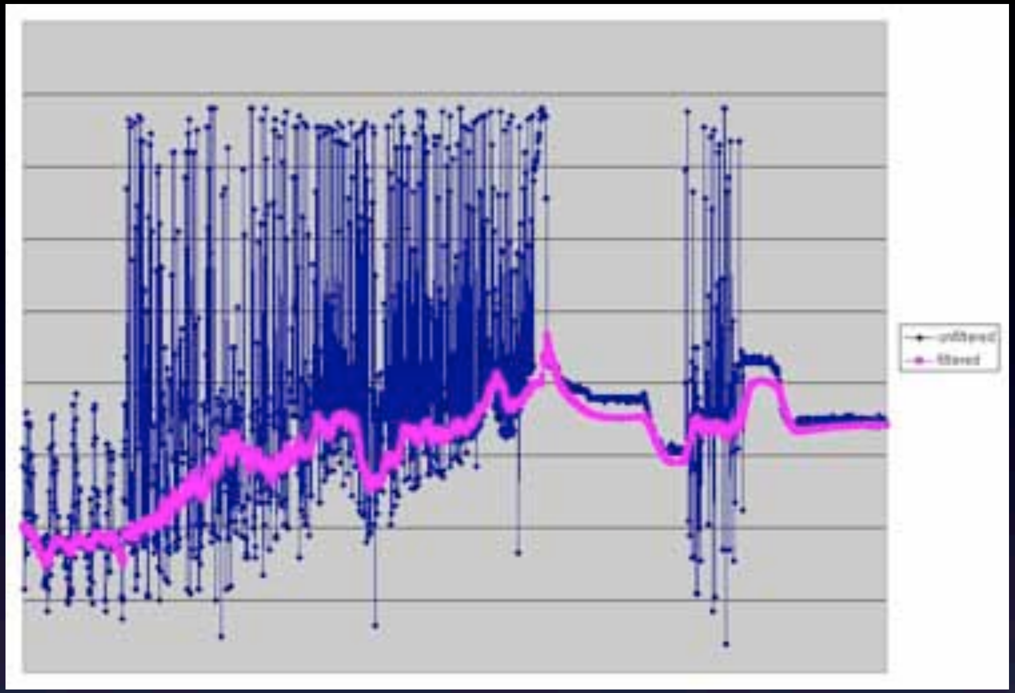
- Vulnerabilities may be in:
  - State estimation
  - Transitions (spoofing or preventing)
  - Unexpected conditions within states

Sensors

- Active vs Passive
- Common sensors:
  - GPS
  - LIDAR
  - Cameras
  - Millimeter Wave Radar
  - Digital Compass
  - IMU
  - Wheel Encoders
  - Doppler Velocity Logger (subsurface)
  - Scanning SONAR (subsurface)
  - Pressure Transducers (air & subsurface)



Sensors

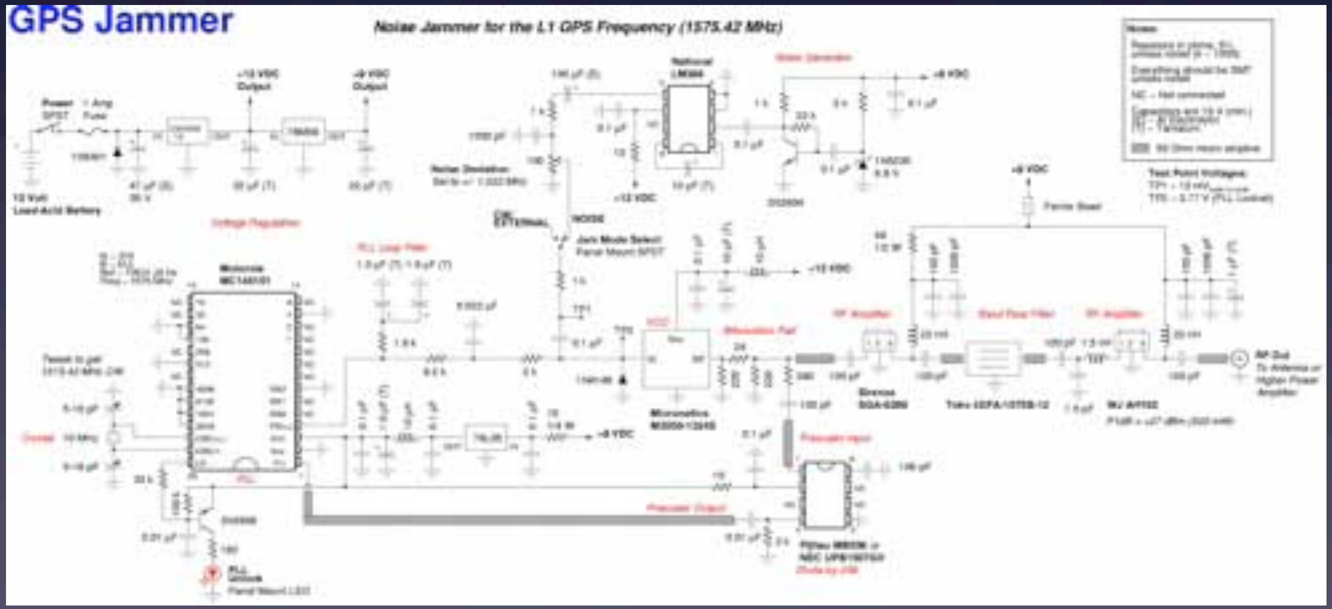


- Sources of uncertainty:
  - Noise
  - Drift
  - Latency & update rate
- Uncertainty must be modeled under assumptions
- Sensor fusion:
  - Fused/registered data can be more useful than separate
  - What to do when sensors disagree?
- Robot robustness may come down to:
  - How smart is it at discounting 1 bad/spoofed sensor?

Sensor Attacks

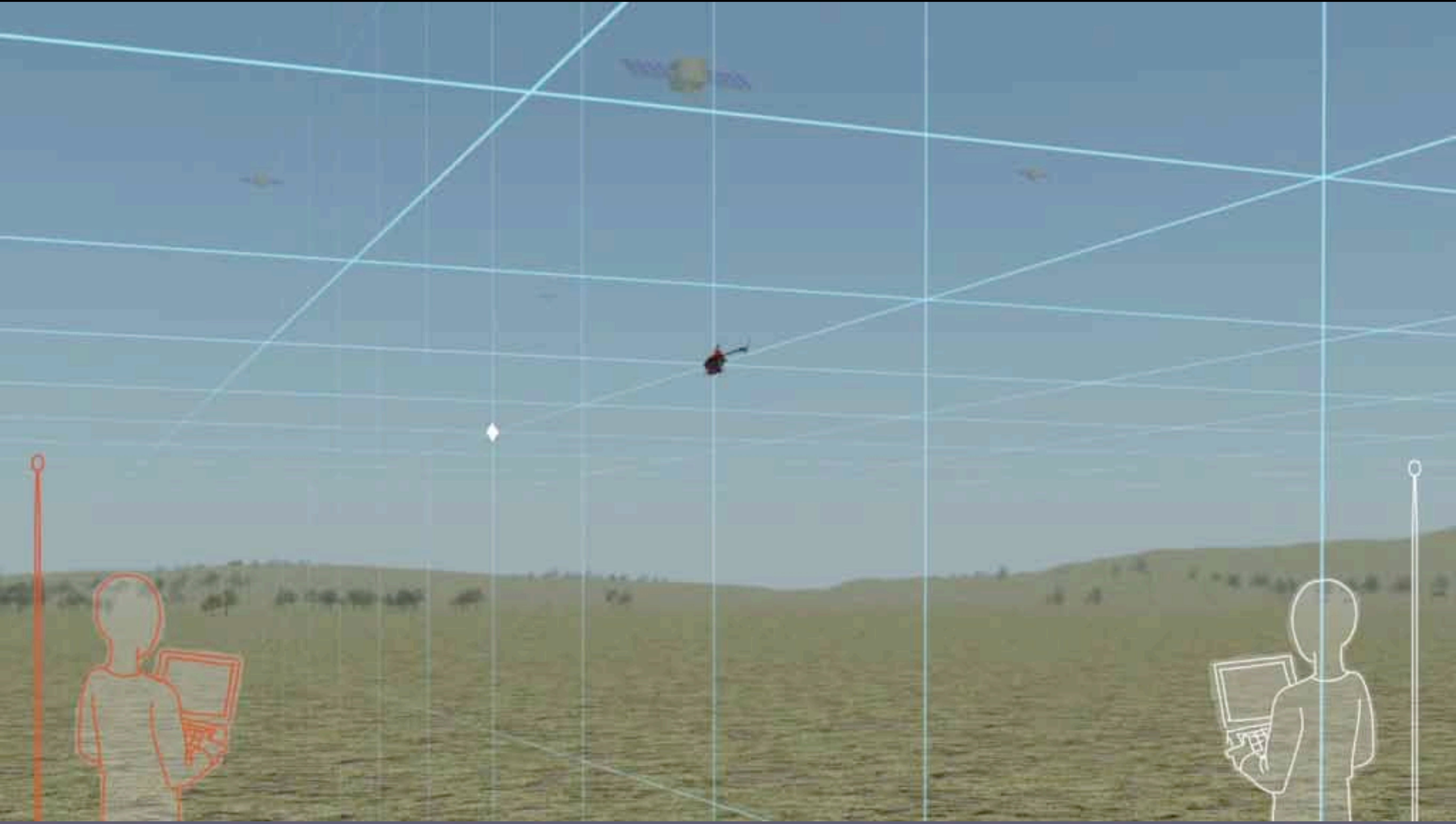
- 2 kinds:
  - Denial
    - Preventing sensor from recovering useful data
  - Spoofing
    - Causing sensor to retrieve specifically incorrect data
- Basic attack mode choice:
  - Attack sensors directly
  - Attack aggregated sensor data

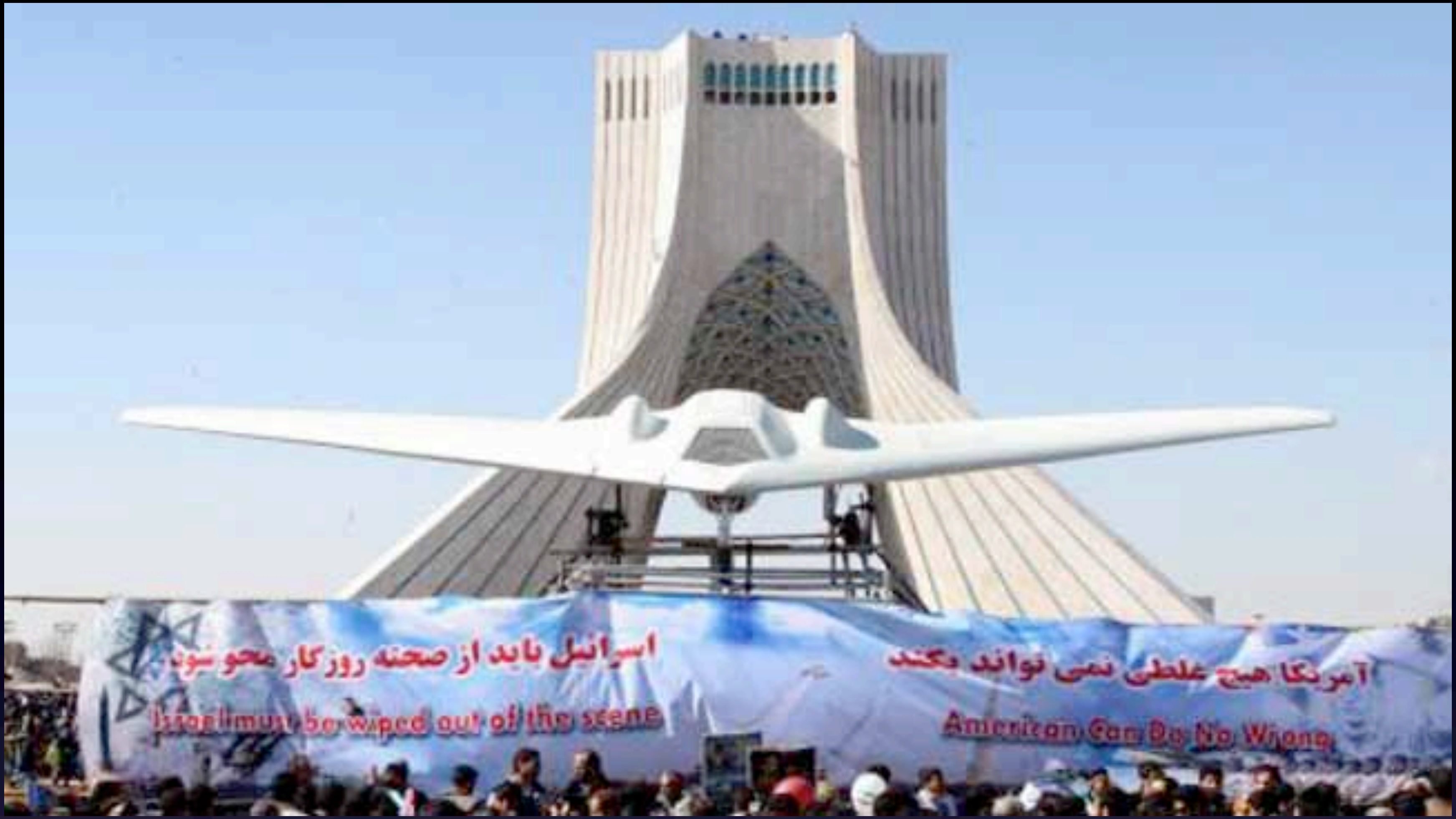
GPS

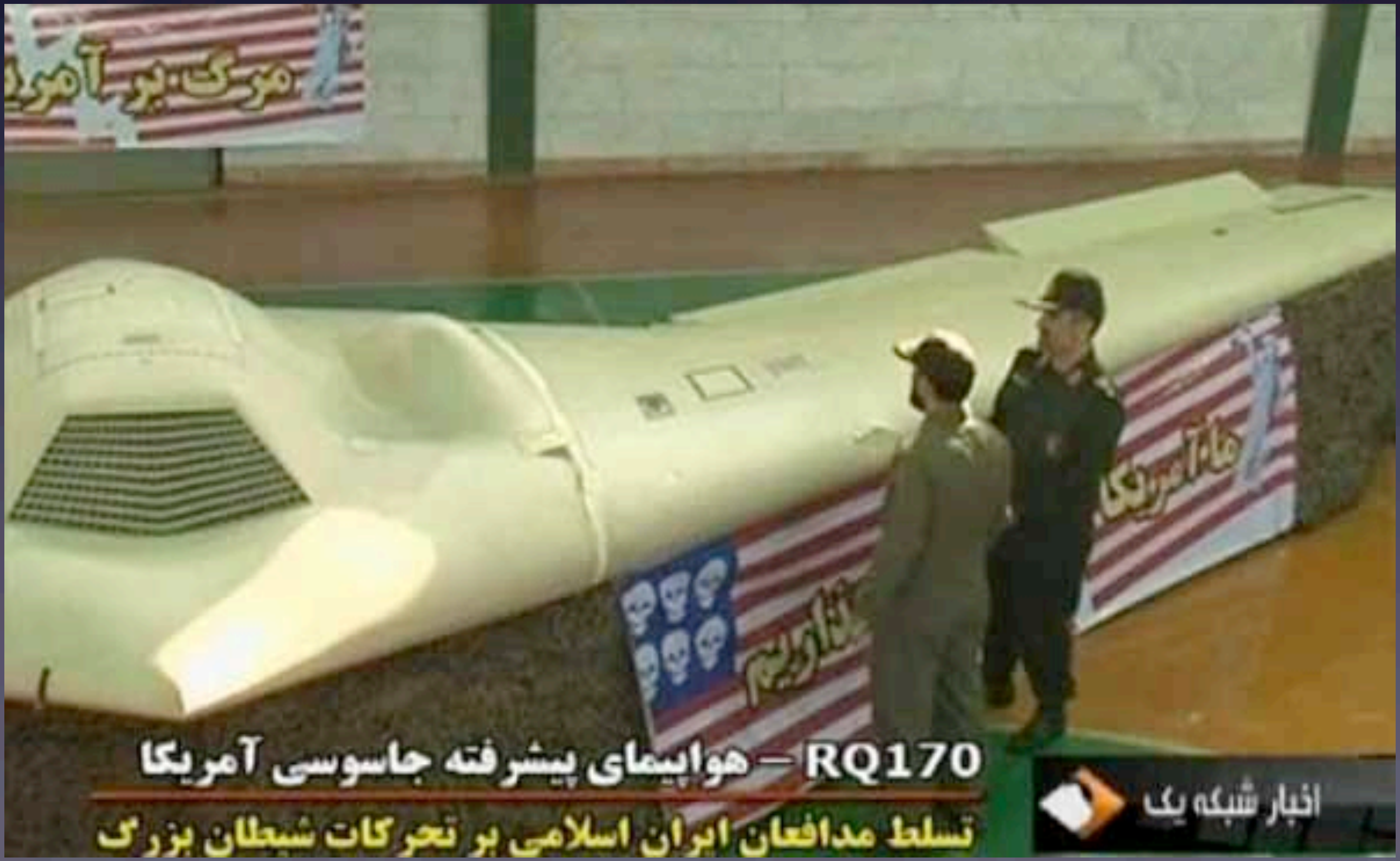


- Denial:
  - Jamming
- Spoofing:
  - Fake GPS satellite signals at higher power

GPS




اسرائیل باید از صحنه روزگار محو شود
Israel must be wiped out of the scene
آمریکا هیچ غلطی نمی تواند بکند
American Can Do No Wrong


مرگ بر آمریکا
RQ170 – هواپیمای پیشرفته جاسوسی آمریکا
تسلط مدافعان ایران اسلامی بر تحرکات شیطان بزرگ
اخبار شبکه یک

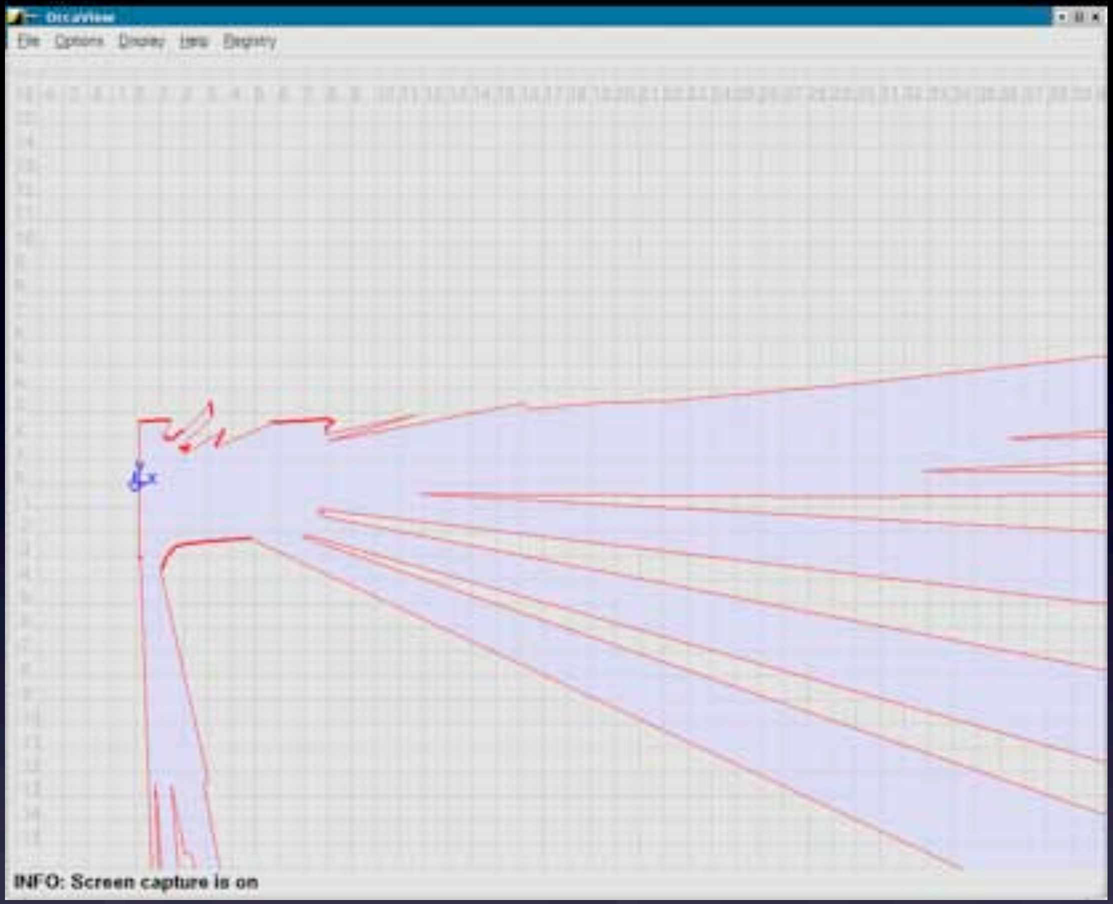
NOVA

02
MY RIDE

LIDAR

- Originally industrial monitoring sensors
- Mechanically scanned operation
- Primarily for collision avoidance & map building
- Denial:
  - Active overpowering
  - Preventing return signal
- Spoofing:
  - Manipulating absorbence/reflectivity

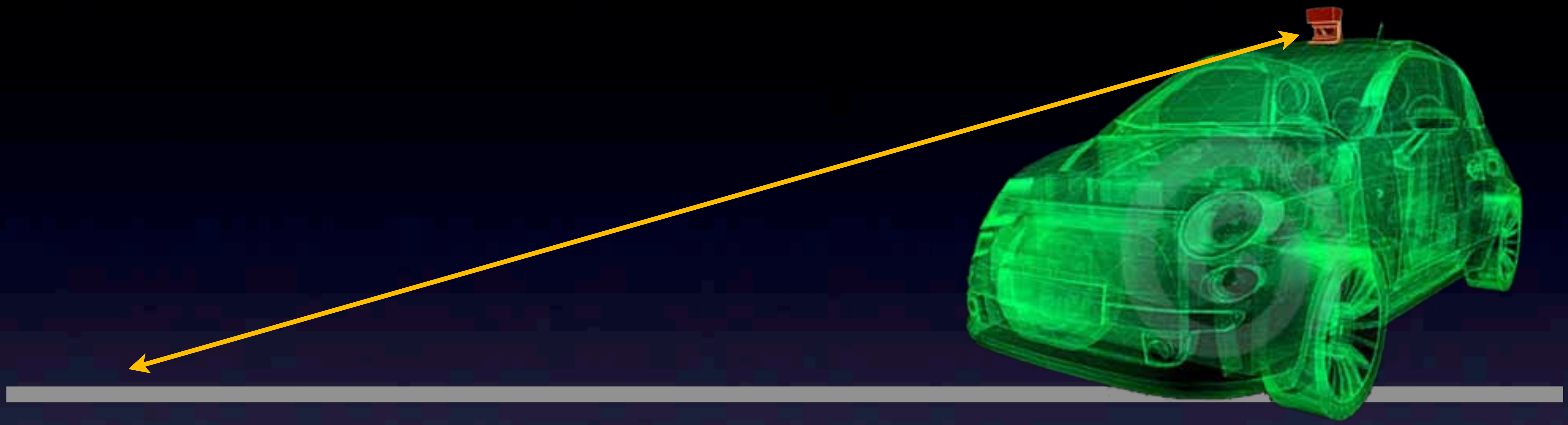
LIDAR



INFO: Screen capture is on

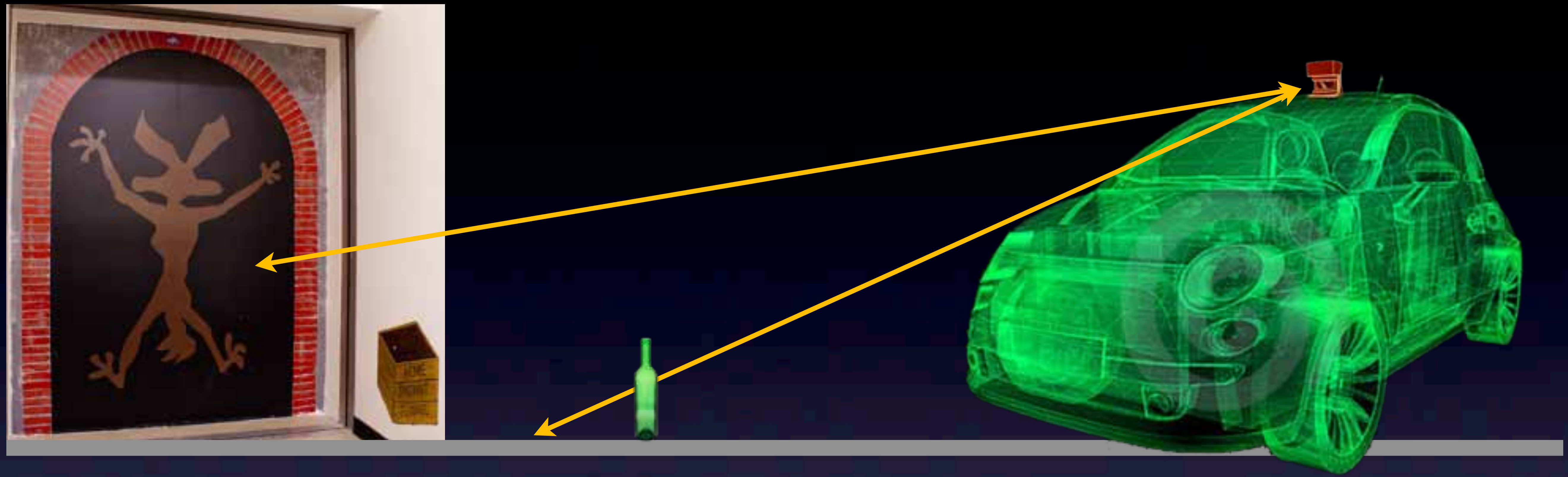
- 2D sensor highly orientation dependent
  - Inclines can look like obstacles
  - May miss low obstacles & discontinuities

LIDAR



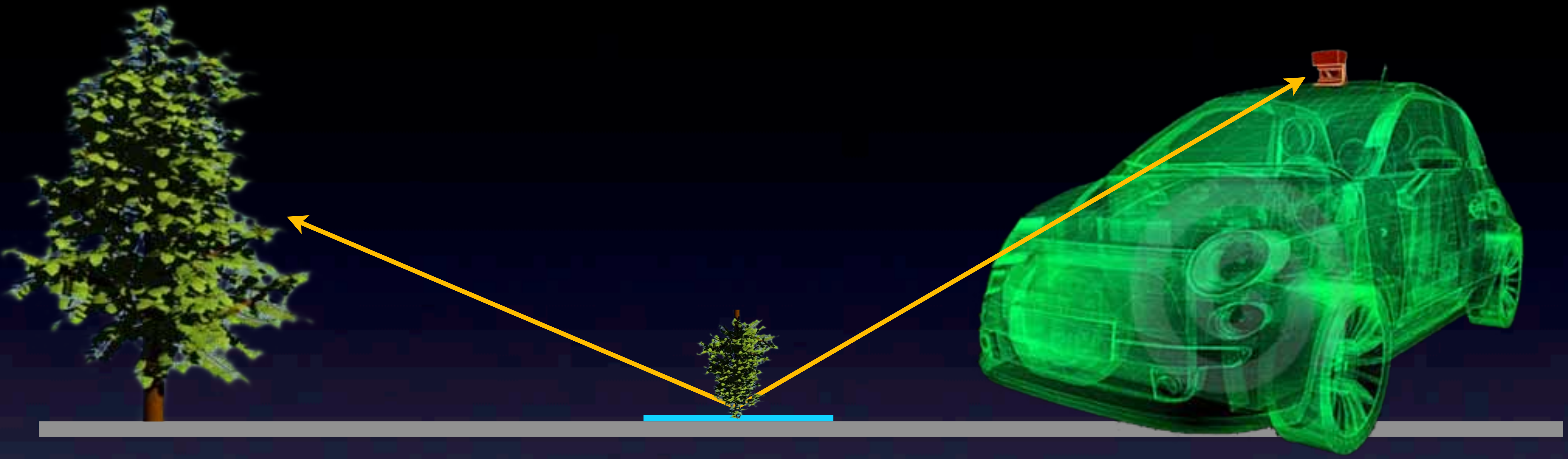
- Active emission sensor
  - Can only see what returns a signal
  - No return = nothing there
  - Most of the world returns no data

LIDAR



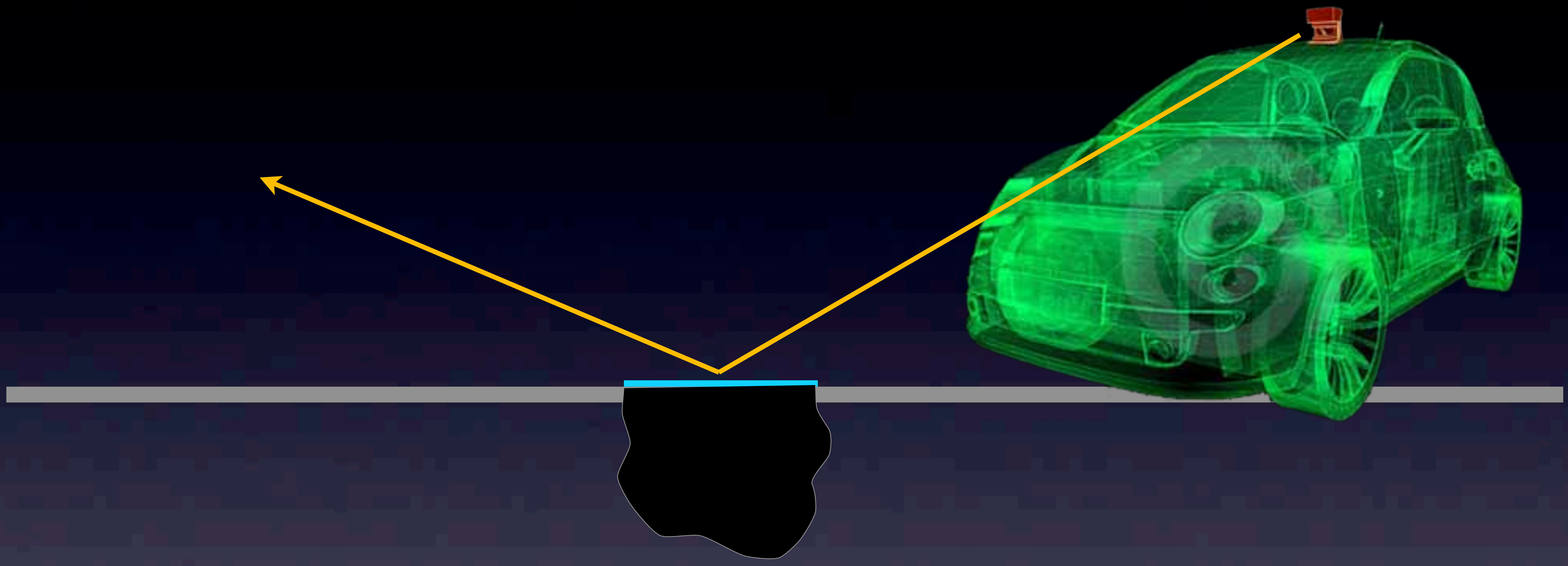
- Absorbent things look like nothing
  - Also transparent

LIDAR



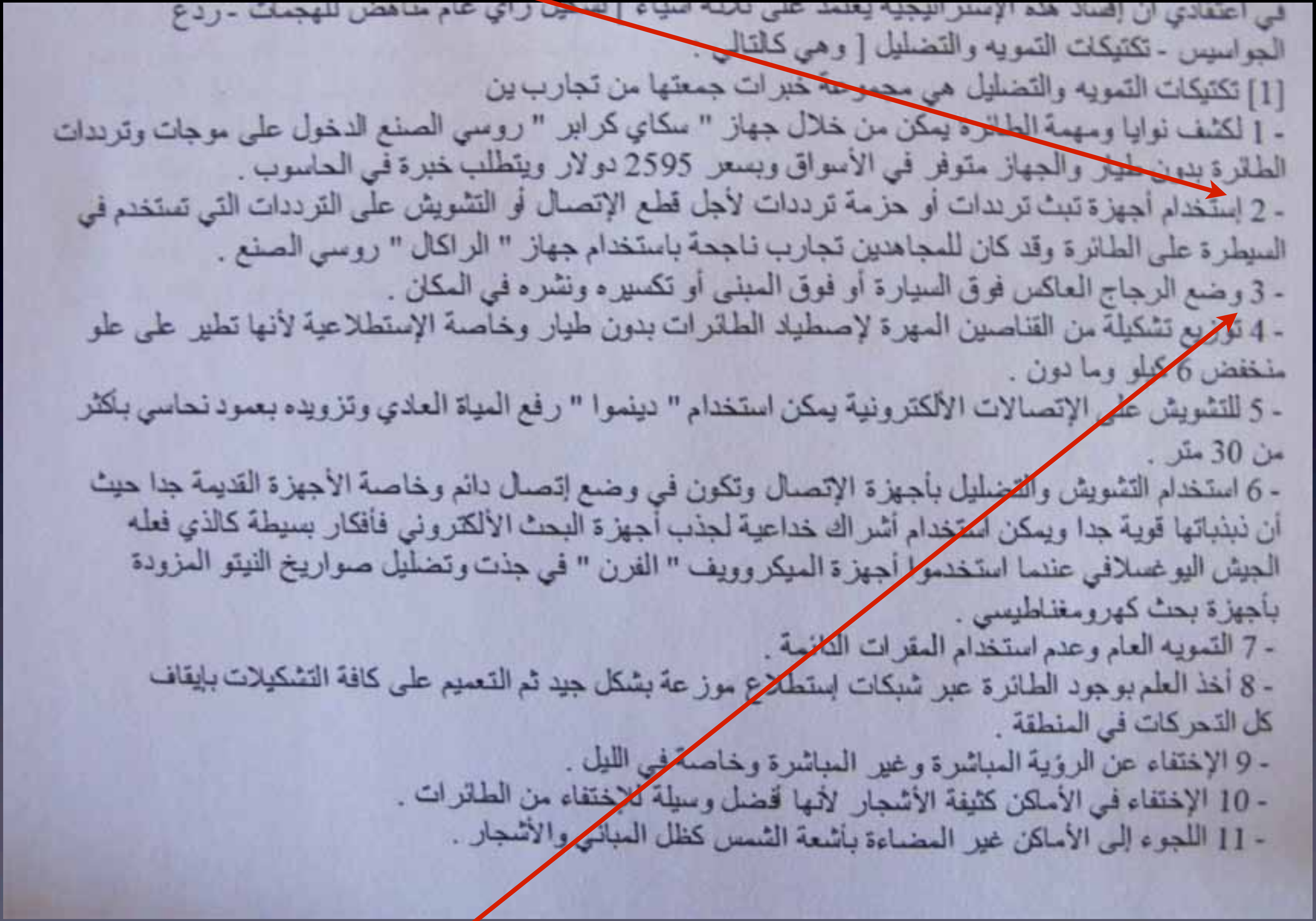
- Reflective things can confuse laser
  - Faraway things brought near
  - Loss of return looks like ditch

LIDAR



- Reflective things can confuse laser
    - Faraway things brought near
    - Loss of return looks like ditch

Russian “Racal” GPS jammer



في أعتقادي أن إفساد هذه الإستراتيجية يعتمد على ثلاثة أشياء [تشكيل رأي عام مناهض للهجمات - ردع الجواسيس - تكتيكات التمويه والتضليل] وهي كالتالي .

[1] تكتيكات التمويه والتضليل هي مجموعة خبرات جمعتها من تجارب ين

- 1 لكشف نوايا ومهمة الطائرة يمكن من خلال جهاز " سكاي كرابر " روسي الصنع الدخول على موجات وترددات الطائرة بدون طيار والجهاز متوفر في الأسواق وبسعر 2595 دولار ويتطلب خبرة في الحاسوب .

- 2 إستخدام أجهزة تبث ترددات أو حزمة ترددات لأجل قطع الإتصال أو التشويش على الترددات التي تستخدم في السيطرة على الطائرة وقد كان للمجاهدين تجارب ناجحة باستخدام جهاز " الراكال " روسي الصنع .

- 3 وضع الرجاج العاكس فوق السيارة أو فوق المبنى أو تكسيره ونشره في المكان .

- 4 توزيع تشكيلة من القناصين المهرة لإصطياد الطائرات بدون طيار وخاصة الإستطلاعية لأنها تطير على علو منخفض 6 كيلو وما دون .

- 5 للتشويش على الإتصالات الألكترونية يمكن استخدام " دينموا " رفع المياة العادي وتزويده بعمود نحاسي بأكثر من 30 متر .

- 6 استخدام التشويش والتضليل بأجهزة الإتصال وتكون في وضع إتصال دائم وخاصة الأجهزة القديمة جدا حيث أن نبذباتها قوية جدا ويمكن استخدام أشراك خداعية لجذب أجهزة البحث الألكتروني فأفكار بسيطة كالذي فعله الجيش اليوغسلافي عندما استخدموا أجهزة الميكروويف " الفرن " في جذت وتضليل صواريخ النيتو المزودة بأجهزة بحث كهرومغناطيسي .

- 7 التمويه العام وعدم استخدام المقرات الدائمة .

- 8 أخذ العلم بوجود الطائرة عبر شبكات إستطلاع موزعة بشكل جيد ثم التعميم على كافة التشكيلات بإيقاف كل التحركات في المنطقة .

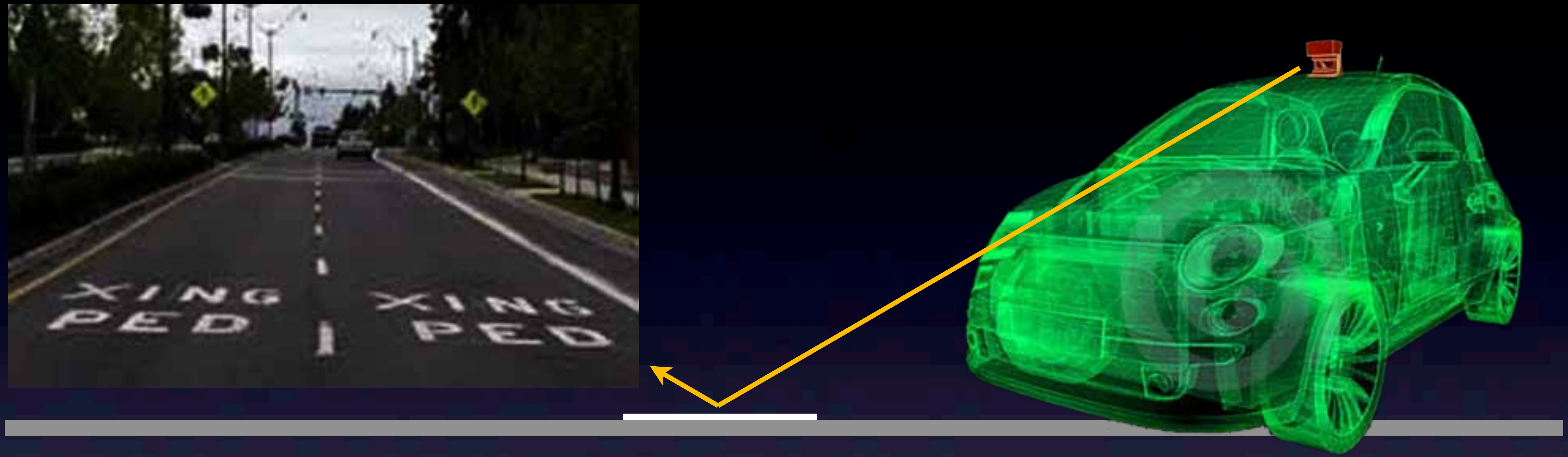
- 9 الإختفاء عن الرؤية المباشرة وغير المباشرة وخاصة في الليل .

- 10 الإختفاء في الأماكن كثيفة الأشجار لأنها قضل وسيلة للإختفاء من الطائرات .

- 11 اللجوء إلى الأماكن غير المضاءة بأشعة الشمس كظل المباني والأشجار .

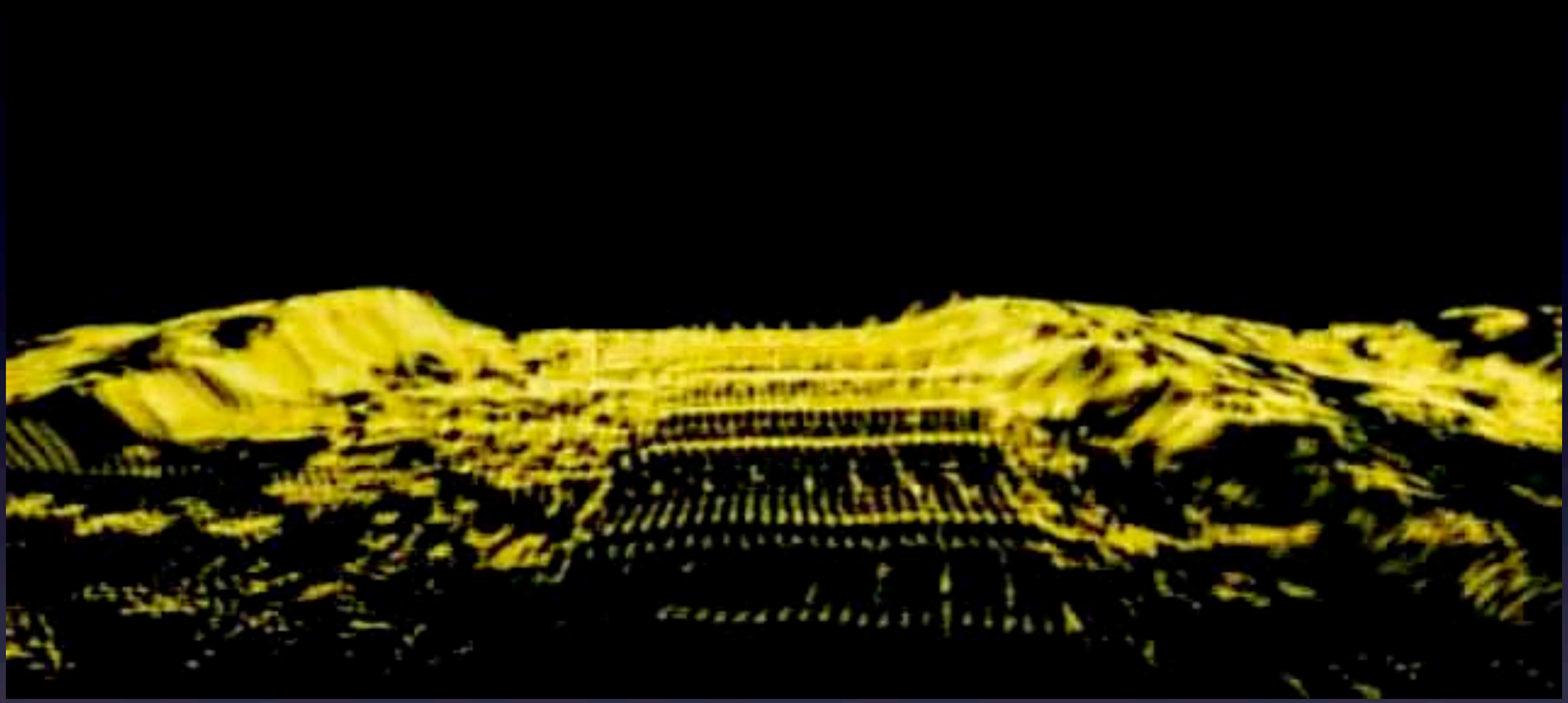
Use of reflective materials
to thwart laser deignators

LIDAR



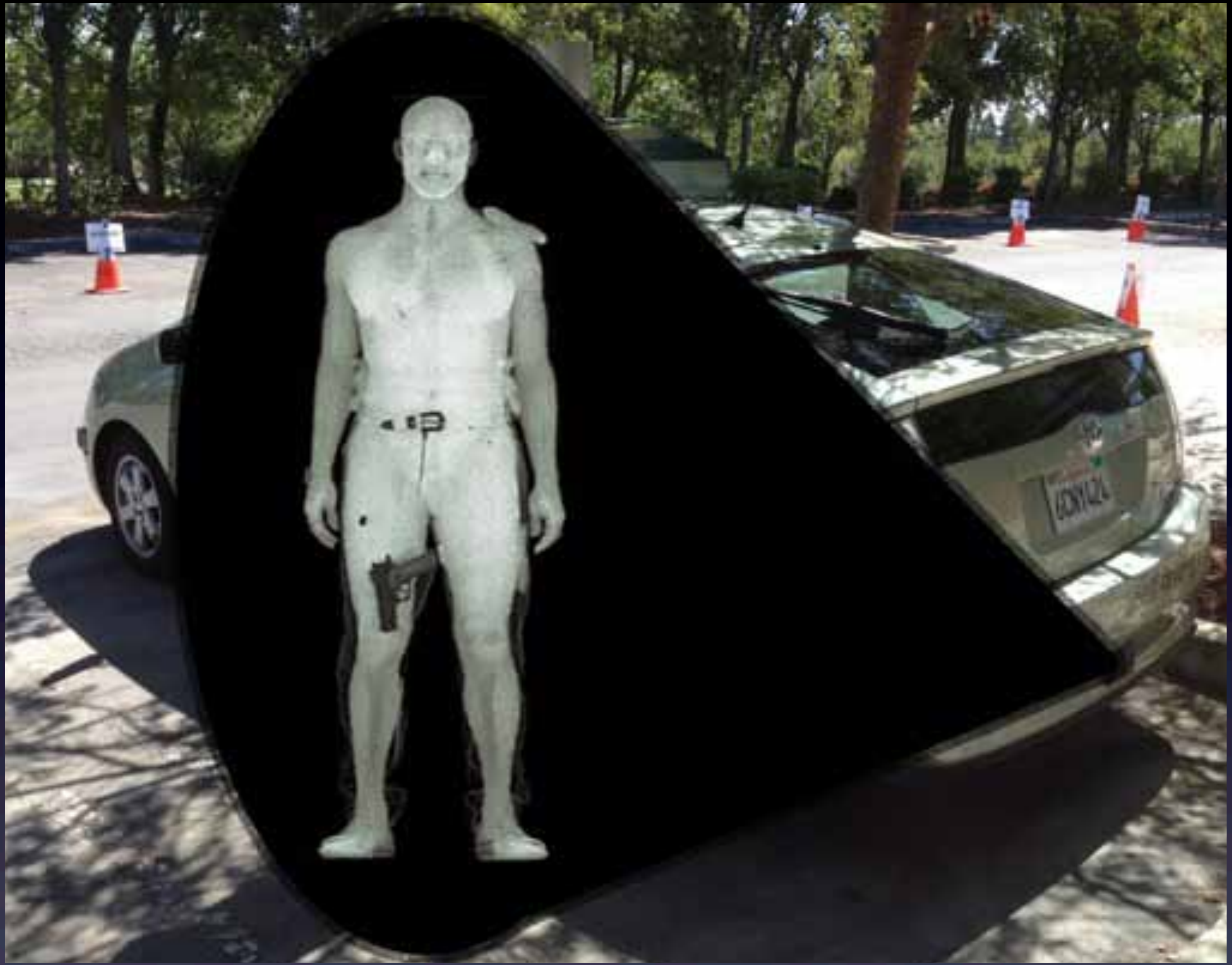
- Reflectance is also a feature
  - Road line detection
  - Can fake road markings invisibly to human

Cameras



- Specialized object detection
- Sometimes stereo for (noisy!) depth map
- Colorizing LIDAR
- Denial:
  - Easily dazzled
- Spoofing:
  - Camouflage techniques
  - Color assumptions
  - Repeating patterns

MMW RADAR

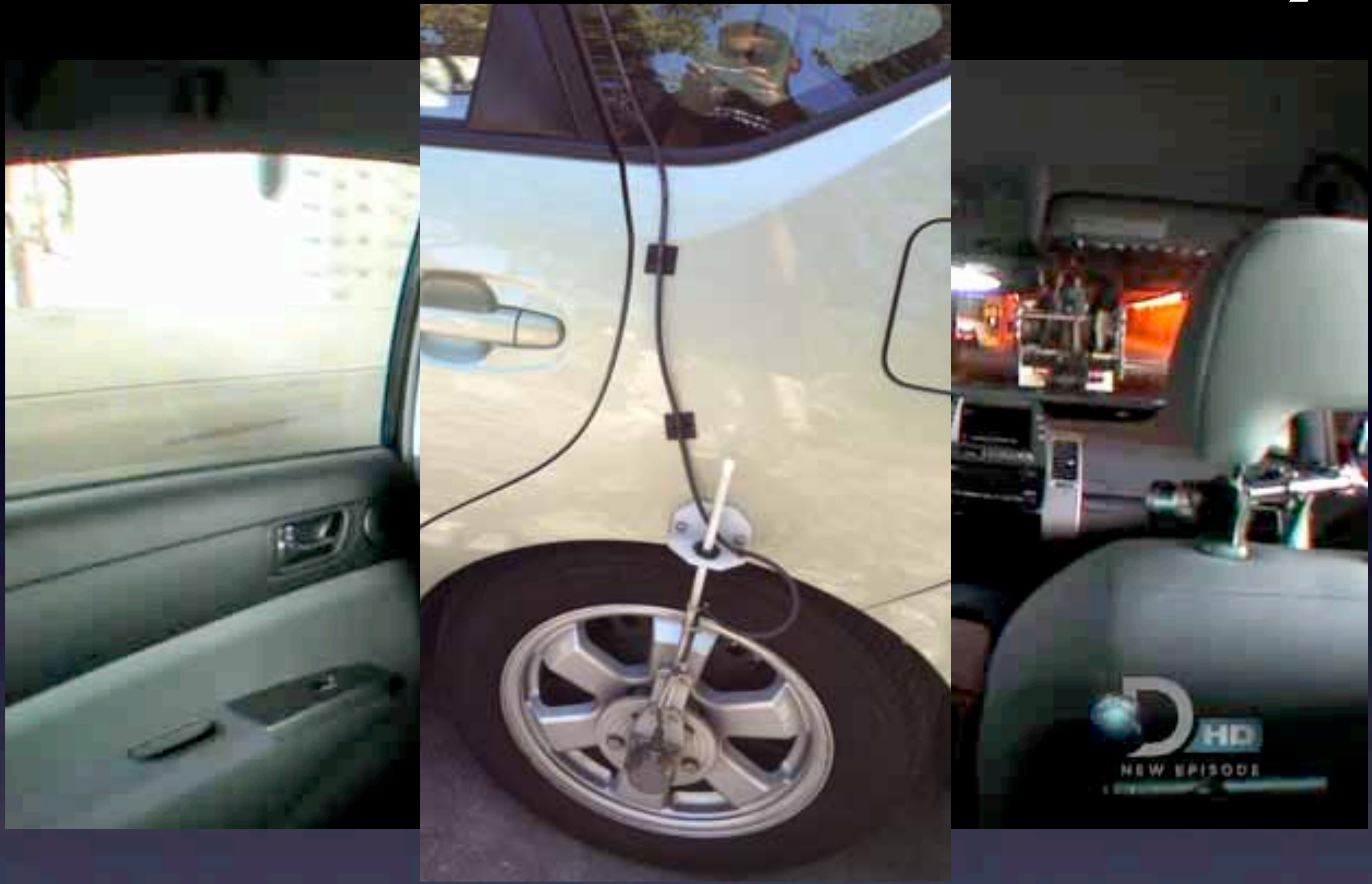


- Collision avoidance
- Lower resolution than laser
- Most things very reflective
- Denial/spoofing:
  - Chaff
  - Overhead signs

IMU & Compass

- Primary navigation sensor for some systems
- High fidelity models available
  - Typical cumulative error: 0.1% of distance traveled
- Denial/spoofing:
  - Extremely difficult to interfere with
  - Physical attack with magnetic fields

Wheel Odometry



- Encoders
- Useful to know true speed & when stopped
- Attacks:
  - Change wheel diameter
  - Slippery surface
  - Removal may cause unpredictable behavior or stoppage

Bond vs Robots

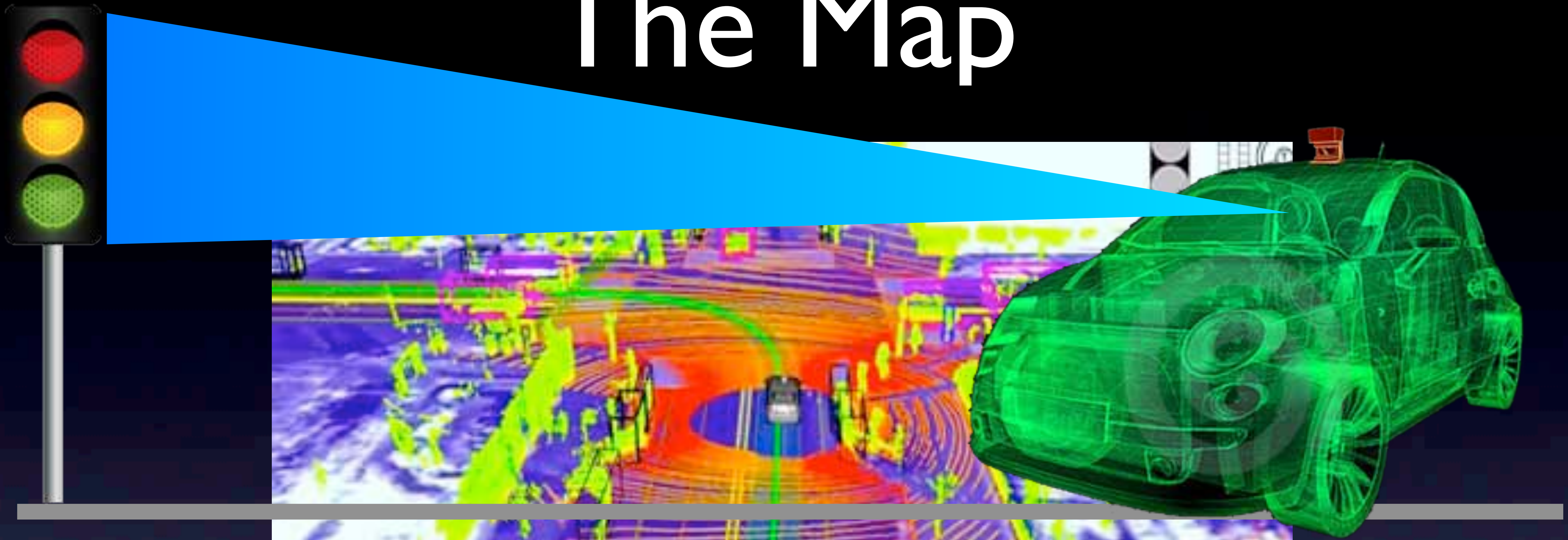
- GPS Jammer
- Smoke/Dust/Vapor
- Chaff
- Glass caltrops
- Oil slick

The Map

HD
NEW EPISODE

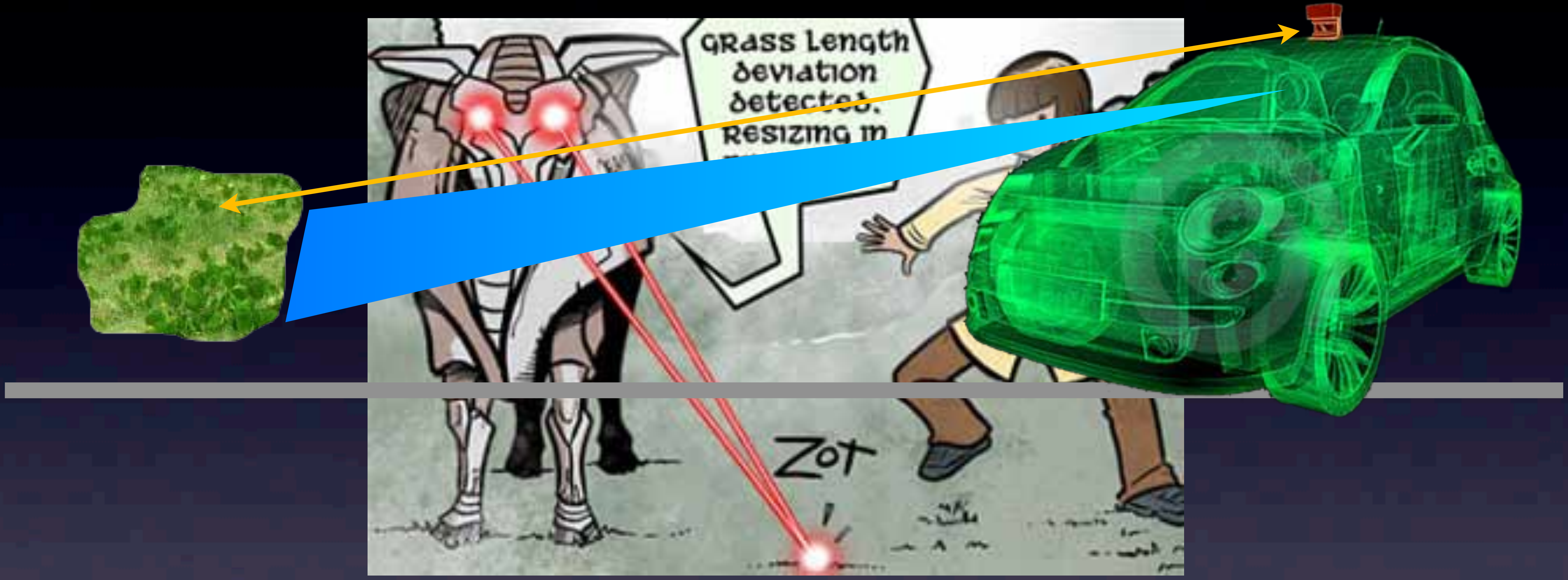
- Great emphasis on preacquired map data
- Often considered to be reference ground truth
- Reduces recognition load
  - Traffic lights
  - Vegetation
  - Other speed control & traffic management features

The Map



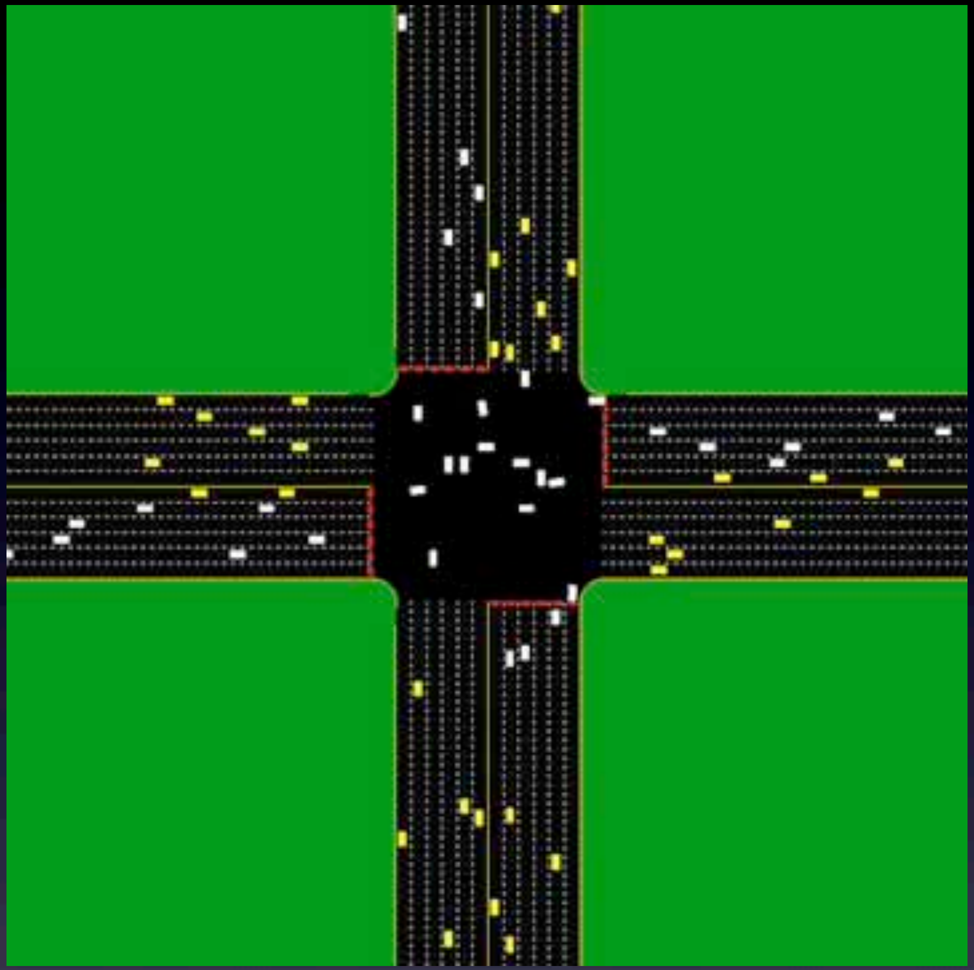
- Traffic lights
  - Camera knows where to look
  - Difference in robot vs human assumptions

The Map



- Vegetation
  - Colorized LIDAR
  - Transmission classifier
- Overhanging foliage
- Map dependence may exacerbate brittleness of discrimination rules

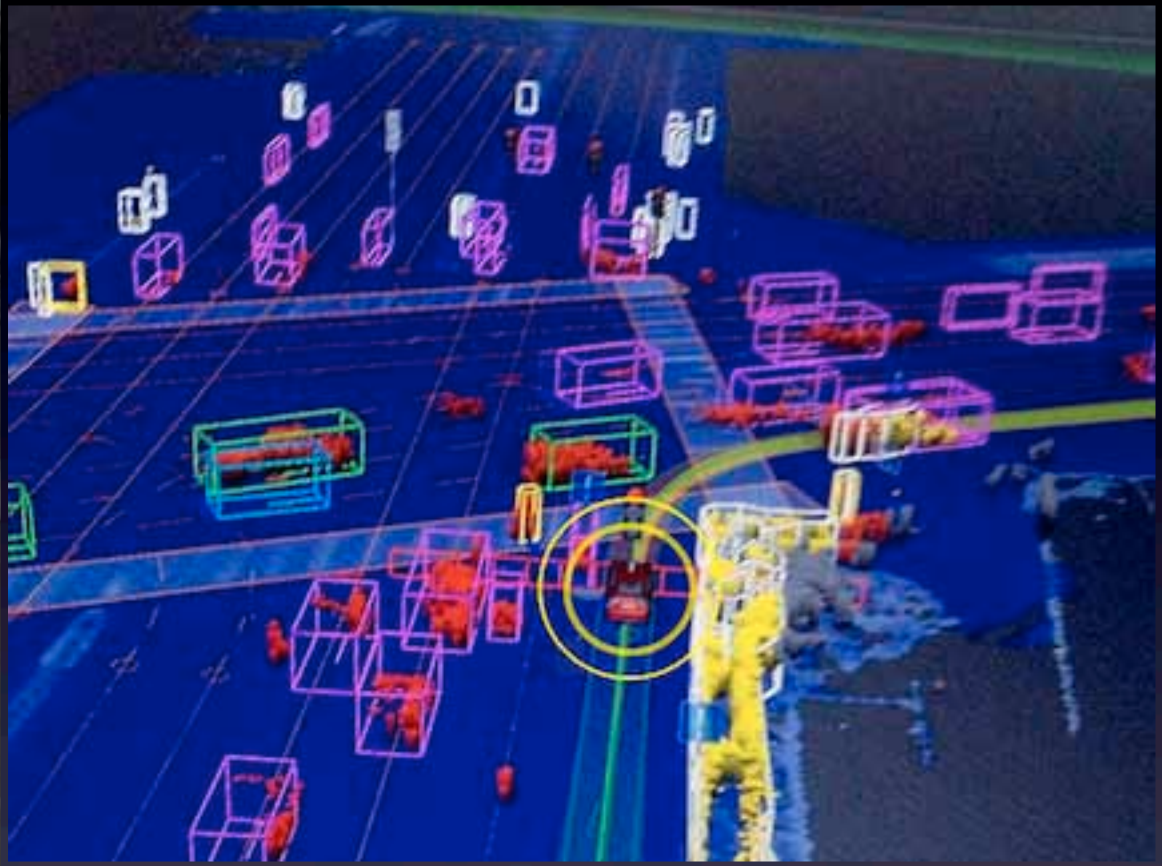
The Map



Peter Stone, UT Austin

- Map requires constant updates
- Local map:
  - Vulnerable to unexpected real world features
- Remote map:
  - Vulnerable to denial (4G jamming)
  - Vulnerable to spoofing (MITM attack, standard cellular intercept techniques)

Exploiting the Logic Structure



- Goal: Maximize uncertainty
  - Requiring manual assistance
  - Confusing/annoying occupants
  - Inconveniencing other road users
- Concentrate on fragile maneuvers

Logic-Based Physical Attacks

- 21st century sabotage
- Dependent on vehicle configuration & mission
- 4G, GPS-enabled electromagnet
  - Near IMU/compass/MMW
- Triggered by map location/activity

Trapping/Redirecting

- Attacks at collision avoidance & navigation layers
- Force robot to postpone high level tasks
  - Moving obstacles
  - Obstacle swarms
  - Artificial stop lights
- Human driver wouldn’t notice, robot can’t ignore

Clobbering

- Goal: make robot run into something
- Subvert collision avoidance
  - Incapacitate vehicle
  - Damage/remove sensors
- Subtle map deviations
- Imitate light vegetation
- Simulate obstacles at speed
- Disguise entrance walls with reflective/absorbent material within GPS noise
- Dynamic obstacles under overhead signs

Remember...

Driverless vehicles are cool!

Don’t do any of these things!

~~Don’t hassle the Hoff!~~

Don’t hax0r the Bots!

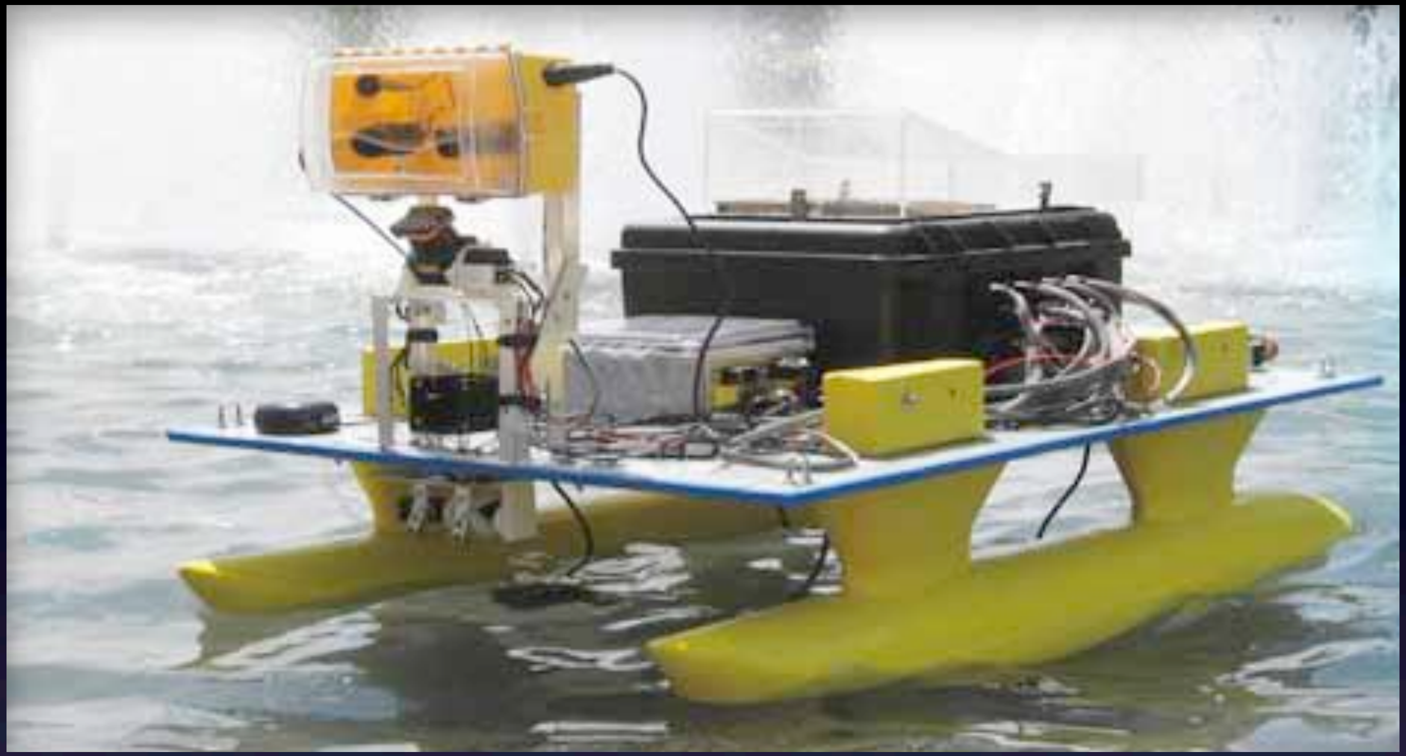
Instead...

Hack *on* them!

SUAS

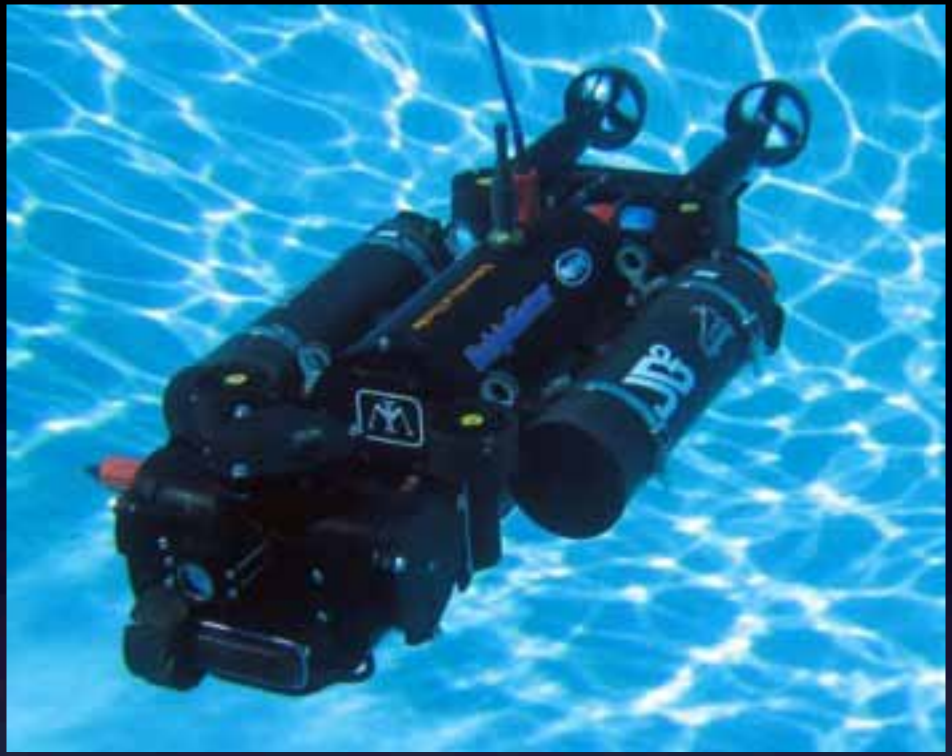
- Tasks:
  - Waypoint navigation
  - Search for & ID secret symbols on ground
  - Connect to narrow-beam wi-fi network
  - Coming soon: package drop?
- Challenges
  - Image/GPS registration
  - Panorama stitching & auto target ID

Roboboat



- Tasks:
  - Channel navigation
  - Direct water cannon on target
  - Identify thermally hot ground item
  - Disable shore-based water spray
  - Deploy ground rover & retrieve package
- Challenges
  - Camera/LIDAR sensor fusion
  - Vegetation/water discrimination
  - Fouling detection

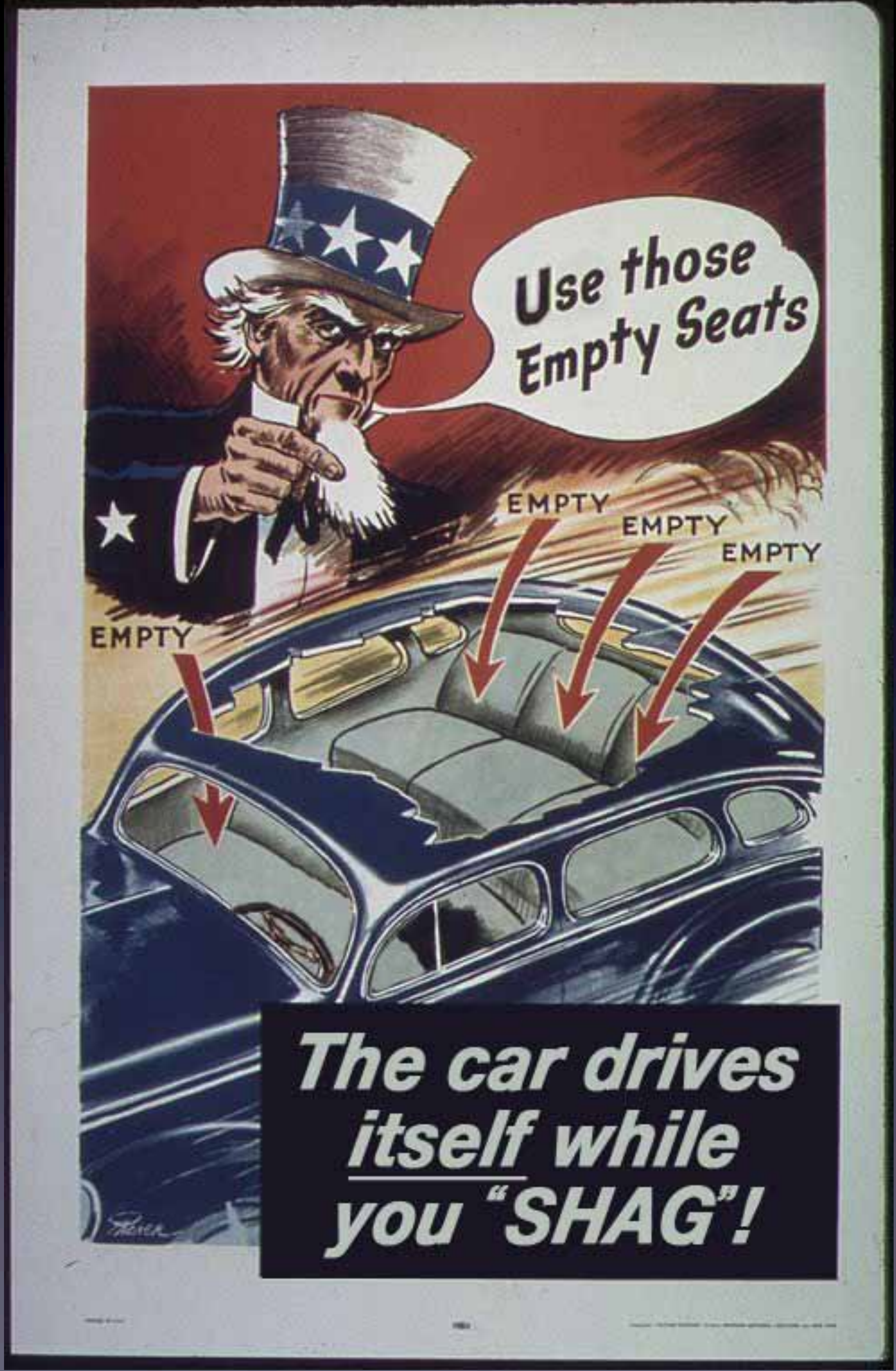
Robosub



- Tasks:
  - 3D Navigation
  - Visual target recognition
  - Torpedo shoot
  - Marker drop
  - Object manipulation
  - SONAR pinger seek & package recovery
- Challenges
  - GPS-free navigation
  - Robust color discrimination
  - Underwater constraints (e.g. thermal management)

Hack The Rules!

- Nontraditional vehicles
- Experimental power supplies
- Dimension limits apply at start only
- Vehicle swarms
- Hacker sports: find loopholes... and exploit them!


Use those Empty Seats
EMPTY
EMPTY
EMPTY
EMPTY
The car drives itself while you "SHAG"!