

 POLITECNICO DI MILANO



# Securing Cyber-Physical Systems: moving beyond fear

Stefano Zanero, PhD  
Associate Professor, Politecnico di Milano



# Welcome to the security circus!



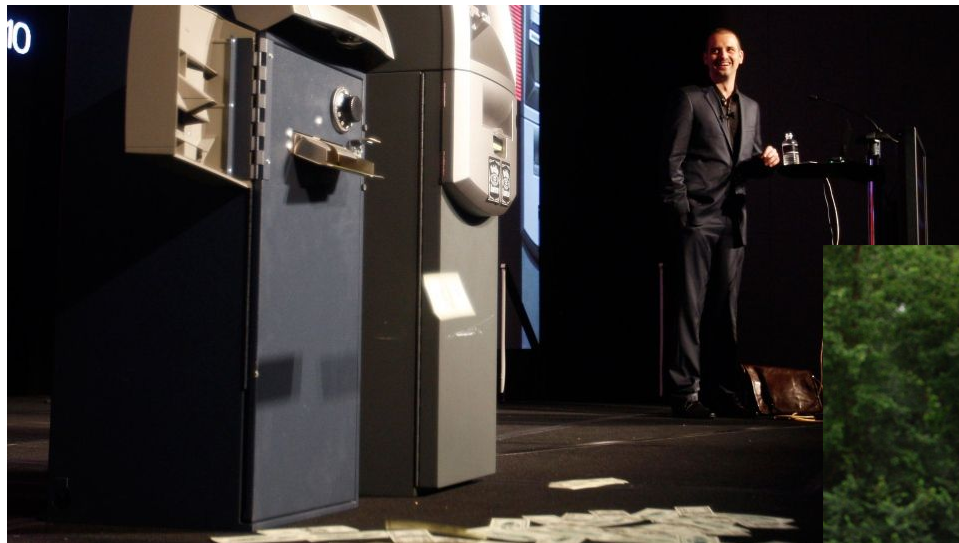


# We all like to see the attractions



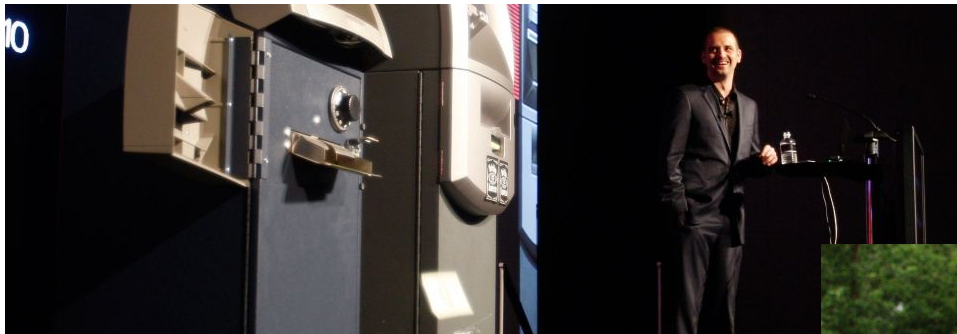


# We all like to see the attractions





# We all like to see the attractions





## And what are the attractions, really?

- Our conferences reward **attack research**
- Because we are hackers at heart and we enjoy the **beauty** of many of these hacks, their skill and their ingenuity
- But you may have realized by now that we are not on IRC in our hacker crews anymore
- We are on the top frontpage news
- Our findings **impact the public perception**



- Costin: “Ghosts in air traffic”
  - Showed a “vulnerability” of ADS-B
  - [https://media.blackhat.com/bh-us-12/Briefings/Costin/BH\\_US\\_12\\_Costin\\_Ghosts\\_In\\_Air\\_Slides.pdf](https://media.blackhat.com/bh-us-12/Briefings/Costin/BH_US_12_Costin_Ghosts_In_Air_Slides.pdf)
  - In reality, ADS-B was designed like this because operationally it is necessary and it is not “insecure”
  - Peer-to-peer value > perceived vulnerability
  - Humans in the loop = low possibility of this leading to lack of safety
- Still, on the media...



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**Andy Greenberg**, Forbes Staff

Covering the worlds of data security, privacy and hacker culture.

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SECURITY | 7/25/2012 @ 1:54PM | 15.906 views

## Next-Gen Air Traffic Control Vulnerable To Hackers Spoofing Planes Out Of Thin Air

 4 comments, 3 called-out

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A hacker attack that leads to planes dropping from the sky is the stuff of every cyberwar doomsday prophesy. But some security researchers imagine a less sensational, if equally troubling possibility: Hundreds or thousands of aircraft radioing their approach to an air traffic control tower, and no way to sort through which are real and which are ghost plane signals crafted by a malicious hacker.







## The crowds are cheering for the lions!

- Hugo Teso: “Aircraft hacking”
  - Used the “vulnerability” of ADS-B to “target a plane”
  - Showed how to exploit a FMS unit bought on eBay
  - Showed how this would affect a plane (on a simulator)
  - <http://conference.hitb.org/hitbsecconf2013ams/materials/D1T1%20-%20Hugo%20Teso%20-%20Aircraft%20Hacking%20-%20Practical%20Aero%20Series.pdf>
  - Later debunked by FAA and expert pilots:  
[http://www.theregister.co.uk/2013/04/13/faa\\_debunks\\_android\\_hijack\\_claim/](http://www.theregister.co.uk/2013/04/13/faa_debunks_android_hijack_claim/)
- Still, on the media...



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### Darlene Storm

*Security Is Sexy*

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## Hacker uses an Android to remotely attack and hijack an airplane

By **Darlene Storm**  
April 10, 2013 4:28 PM EDT [230 Comments](#)

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The [Hack in the Box \(#HITB2013AMS\)](#) security conference in Amsterdam has a very interesting lineup of talks [[pdf](#)]. One that jumped out was the [Aircraft Hacking: Practical Aero Series](#) presented by [Hugo Teso](#), a security consultant at n.runs in Germany. According to the abstract, "This presentation will be a practical demonstration on how to remotely attack and take full control of an aircraft, exposing some of the results of my three years research on the aviation security field. The attack performed will follow the classical methodology, divided in discovery, information gathering, exploitation and post-exploitation phases. The complete attack will be accomplished remotely, without needing physical access to the target aircraft at any time, and a testing laboratory will be used to attack virtual airplanes systems."



ALTRI ARTICOLI DI  
**Tecnologia**



**Cybercrimine finanziario e spionaggio: il 2012 è stato messo alla prova così**



**Twitter prova a blindarsi dopo gli attacchi, lavora a doppia chiave di autenticazione**

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Sei in: [Repubblica](#) > [Tecnologia](#) > L'hacker che voleva dirottare un aereo ...



6



16



133

## L'hacker che voleva dirottare un aereo con lo smartphone e una piccola app

Hugo Teso ha stupito la platea in una conferenza svoltasi nei giorni scorsi ad Amsterdam: è riuscito a cambiare la traiettoria e la velocità di un aereo virtuale cliccando su una mappa sul suo smartphone Android o facendo oscillare il telefono. Ma gli esperti rassicurano: lo ha fatto su un simulatore, software che non ha certo le protezioni di un vero velivolo

di *MATTEO CAMPOFIORITO*

Lo leggo dopo



"UNO SMARTPHONE Android e il programma giusto. Tanto basta per dirottare un aereo". A parlare è l'hacker Hugo Teso che alla conferenza Hack In The Box, nei giorni scorsi ad Amsterdam, ha stupito la platea con una presentazione che descrive come sia possibile prendere il controllo di un velivolo sfruttando delle vulnerabilità nei sistemi di controllo degli aerei di linea. Ma dall'European Aviation Safety Agency, l'ente che si occupa della



## Resulting public perception...





## Why is this the case with cyber-physical systems in particular?

- They are systems that people **see** and can immediately perceive as **relevant**



# The great cyberfear is spreading

“... potential (cyber)attacks against network infrastructures may have widespread and devastating consequences on our daily life: *no more electricity or water at home, rail and plane accidents, hospitals out of service*”

Viviane Reding

VP of European Commission (at time of delivering these remarks)



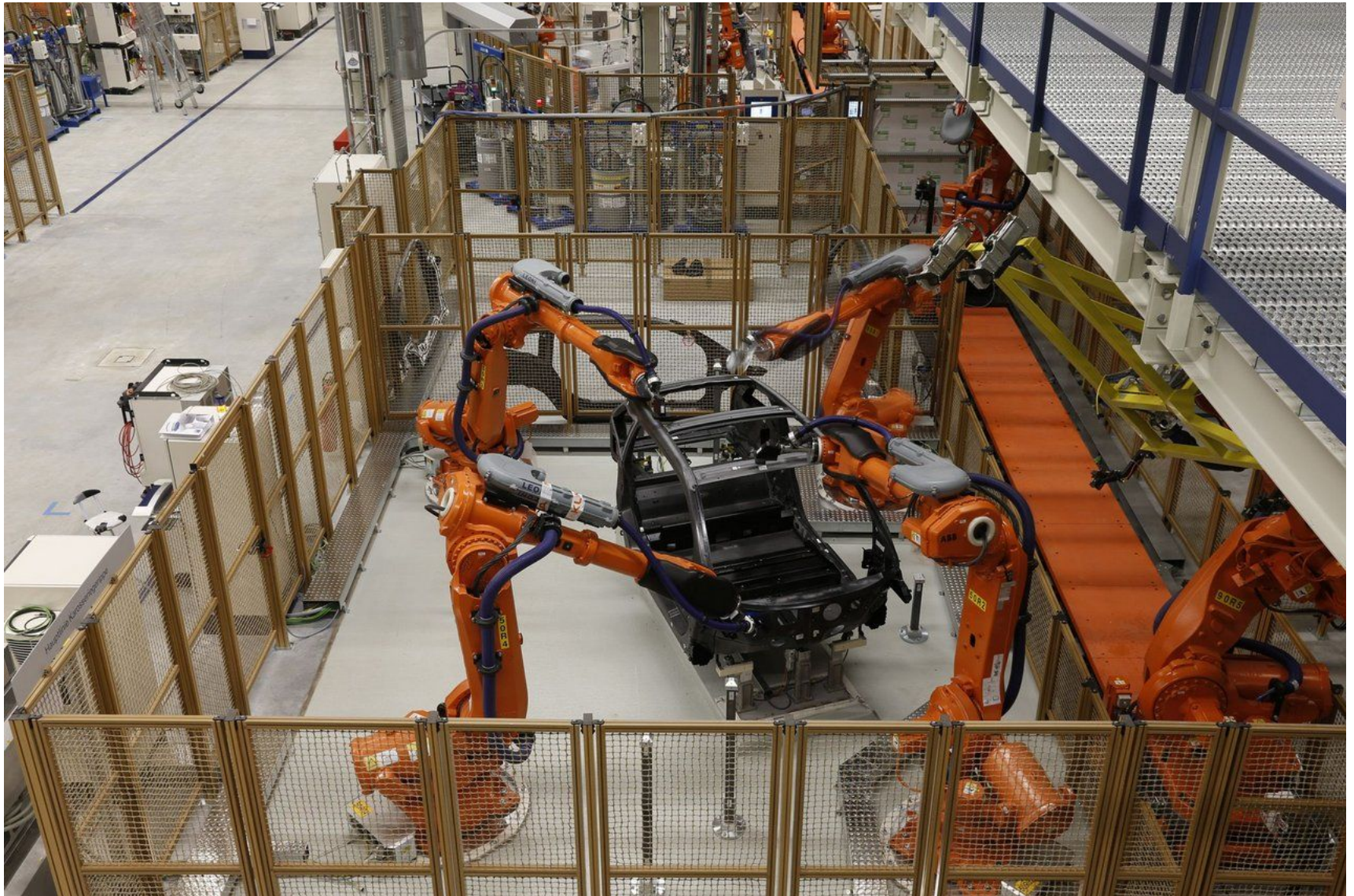


## Why is this the case with cyber-physical systems in particular?

- They are systems that people **see** and can immediately perceive as **relevant**
- They are systems with **safety** constraints which may involve danger for **human life**



For instance, industrial robots...







... are getting out of their cages





## Why is this the case with cyber-physical systems in particular?

- They are systems that people **see** and can immediately perceive as **relevant**
- They are systems with **safety** constraints which may involve danger for **human life**
- They are systems that are becoming more and more reliant on automation (think: autonomous vehicles!)



# Automation has always evoked fear



BRIDGE  
CHECKERS  
CHESS  
POKER  
FIGHTER COMBAT  
GUERRILLA ENGAGEMENT  
DESERT WARFARE  
AIR-TO-GROUND ACTIONS  
THEATERWIDE TACTICAL WARFARE  
THEATERWIDE BIOTOXIC AND CHEMICAL WARFARE  
GLOBAL THERMONUCLEAR WAR





## We can't just keep the circus going!

- “Stunt hacks” have been important in **raising awareness** and in opening up discussions in the industry
- However, they focus on specific **vulnerabilities**



“Bruce Schneier asked a cogent, first-principles question: Are vulnerabilities in software dense or sparse? If they are sparse, then every vulnerability you find and fix meaningfully lowers the number of vulnerabilities that are extant. If they are dense, then finding and fixing one more is essentially irrelevant to security and a waste of the resources spent finding it.”



Dan Geer



## We can't just keep the circus going!

- “Stunt hacks” have been important in **raising awareness** and in opening up discussions in the industry
- However, they focus on specific **vulnerabilities**
- **We are not going to solve anything by just squashing one vulnerability at a time!**



A flaw that Brad Spengler [...] has been incessantly pointing out for years [is] that **bugs don't matter**. Bugs are irrelevant. Yet our industry is fatally focused on what is essentially vulnerability masturbation. [...]

And it's all bullshit. If you care about security that is. [...]

"But to stop exploitation you have to understand it!". Sure. But here's an inconvenient truth. **You are not going to stop exploitation. Ever.**

So if you truly, deeply, honestly care about security. Step away from exploit development. All you're doing is ducking punches that you knew were coming. It is moot. It is not going to stop anyone from getting into anything, it's just closing off a singular route.

But if you care about systemic security [...] **don't chase and fix vulnerabilities, [...] design a system around fundamentally stopping routes of impact.**

Containment is the name of the game. Not prevention. The compromise is inevitable and the routes are legion. It is going to happen.



## We can't just keep the circus going!

- “Stunt hacks” have been important in **raising awareness** and in opening up discussions in the industry
- However, they focus on specific **vulnerabilities**
- **We are not going to solve anything by just squashing one vulnerability at a time!**
- In the specific case of CPS we need to **restore confidence** in the public and in our colleagues in other areas of the profession





## How do we fix this?

- I'm sorry, I don't believe I have a **solution**, but I definitely have two **suggestions**
- First, we need to think systemically, and not of the specific vuln, let me use an example you all know well...



Example:

  
**black hat**<sup>®</sup>  
USA 2017

JULY 22-27, 2017  
MANDALAY BAY / LAS VEGAS



POLITECNICO  
MILANO 1863

DIPARTIMENTO DI ELETTRONICA  
INFORMAZIONE E BIOINGEGNERIA

# Breaking the Laws of Robotics

## Attacking Industrial Robots

Davide Quarta, Marcello Pogliani, Mario Polino, Federico Maggi,  
Andrea M. Zanchettin, Stefano Zanero

 #BHUSA / @BLACKHATEVENTS



# What the circus cheered for:



## Update problems



FlexPendant

Axis Computer

Microcontrollers

### How? FTP at boot

```
FTP 116 Request: SIZE /hd0a/ROBOTWARE_5.13.1037/TPS//SxTPU/2.0/TpsStart.exe
FTP 66 Response: 213 415744
FTP 116 Request: RETR /hd0a/ROBOTWARE_5.13.1037/TPS//SxTPU/2.0/TpsStart.exe
FTP 95 Response: 150 Opening BINARY mode data connection
```

.... plus, no code signing, nothing

[#BHUSA](#) / [@BLACKHATEVENTS](#)



# What the circus cheered for:



## Update problems

→ FlexPendant



## Autoconfiguration is magic!

### How? FTP at boot

|     |     |          |
|-----|-----|----------|
| FTP | 116 | Request  |
| FTP | 66  | Response |
| FTP | 116 | Request  |
| FTP | 95  | Response |

.... plus, no code signing, r

```

FTP      117 Response: 220 ABB Robotics FTP server (VxWorks5.5.1) ready.
FTP      84 Request: USER _SerB0xFtp_
FTP      89 Response: 331 Password required
FTP      81 Request: PASS ██████████
FTP      86 Response: 230 User logged in
FTP      72 Request: PASV
FTP      114 Response: 227 Entering Passive Mode (192,168,125,1,4,25)
FTP      93 Request: RETR /command/startupInfo
FTP      107 Response: 150 Opening BINARY mode data connection
FTP      89 Response: 226 Transfer complete
FTP      72 Request: QUIT
FTP      91 Response: 221 Bye...see you later

```



ABBVU-DMRO-124642

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# What the circus cheered for:



## Update problems

→ FlexPendant



## Autoconfiguration is magic!



## Enter /command

Let's look at `cmddev_execute_command`:

`shell` → `sprintf(buf, "%s", param)`

other commands → `sprintf(buf, "cmddev_%s", arg)`

overflow `buf` (on the stack) → **remote code execution**

1) ready.

L,4,25)



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ABBVU-DMRO-128238

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# What the press impact was:

## Catastrophe Warning: Watch An Industrial Robot Get Hacked



EDITOR'S PICK  
**Thomas Fox-Brewster** Forbes Staff  
May 3, 2017, 08:00am • 3,154 views • #CyberSecurity



ABB has fixed vulnerabilities in its robots that allowed hackers to remotely change its configuration, opening the door for catastrophic results, researchers warned Wednesday. (Photo credit: SAM YEH/AFP/Getty Images)



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ANDY GREENBERG SECURITY 05.03.17 08:00 AM

## WATCH HACKERS SABOTAGE AN INDUSTRIAL ROBOT ARM





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### MOTHERBOARD

INTERNET INSECURITY | By Lorenzo Franceschi-Bicchieri | May 3 2017, 2:01pm

# Hackers Are Remotely Controlling Industrial Robots Now

Security researchers have found multiple vulnerabilities into a specific model of robot arm used in factories.

ANDY GREENBERG SECURITY 05.03.17 08:00 AM

# WATCH HACKERS SABOTAGE AN INDUSTRIAL ROBOT ARM

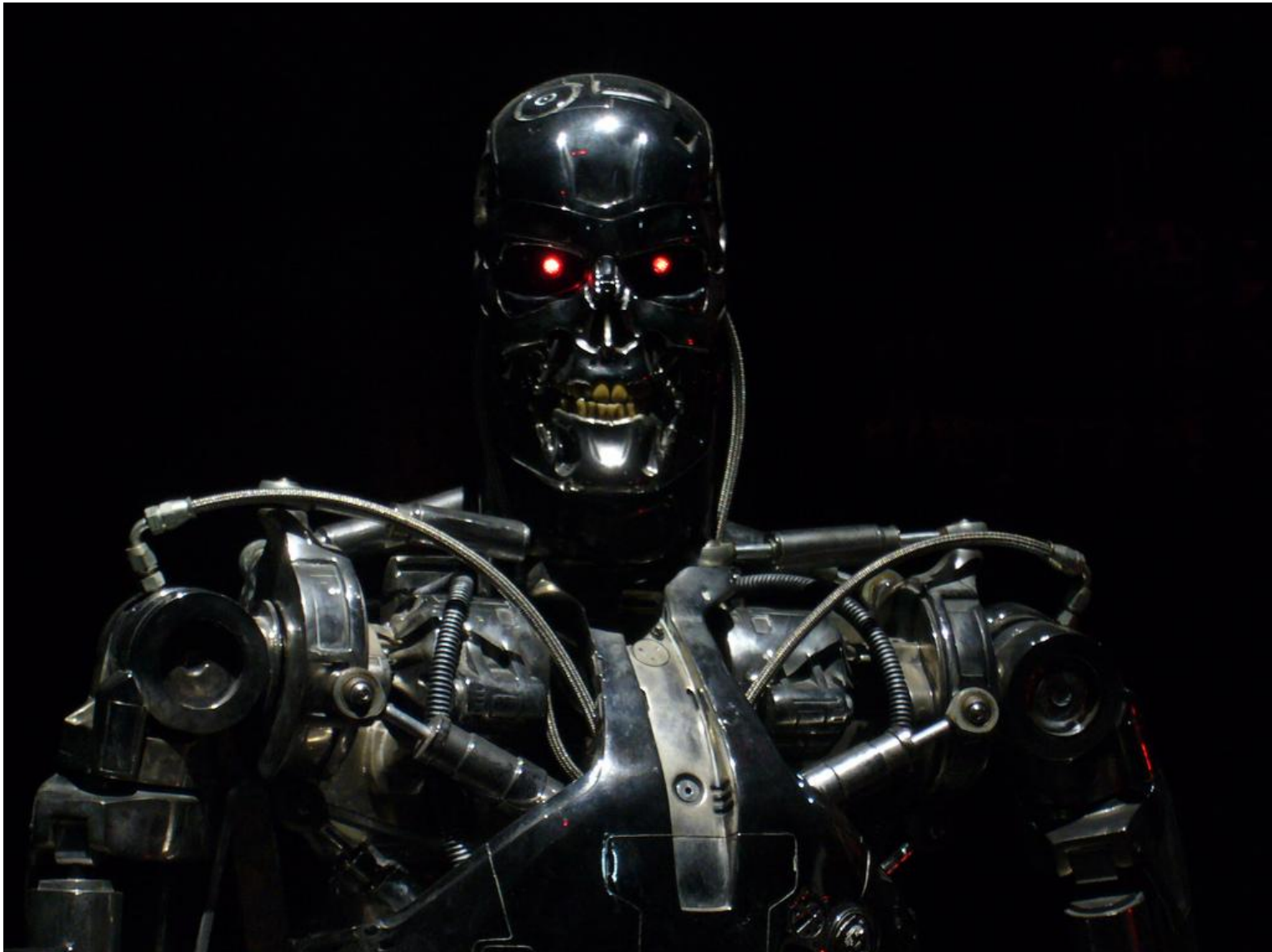


ABB has fixed vulnerabilities into a specific model of robot arm used in factories, resulting in catastrophic results, researchers say.





## What the public perception was:





## What was actually important in the paper:

- We explored the domain-specific **post-exploitation strategies** (which leads to intuitive ways to close them off)
- We explored the **threat landscape** to identify ways to minimize **impact**
- We explored **architectural changes** that would improve **resilience** (e.g. firmware signatures)
- We proposed **research directions** to further improve security of industrial robots (e.g. static analysis of domain specific languages)
- We identified **industrial routers** as an appealing target for further investigation



## How do we fix this?

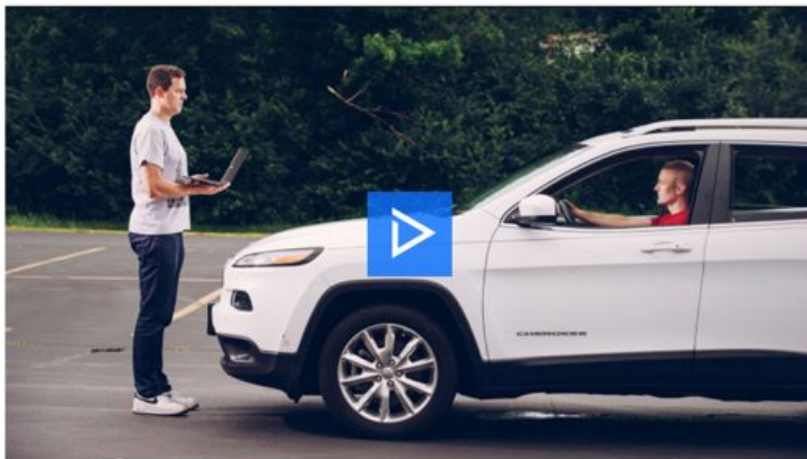
- I definitely have two **suggestions**
- First, we need to think systemically, and not of the specific vulnerability, but rather of its **impact**, of **resilience strategies**, of **architectural changes...**
- Second, we need to embed security in the **design process**, and to make security decisions **risk-driven**. Let me use the automotive industry as an example.



# Multiple attacks and hacks (local and remote)

ANDY GREENBERG SECURITY 07.21.15 6:00 AM

## HACKERS REMOTELY KILL A JEEP ON THE HIGHWAY —WITH ME IN IT



I WAS DRIVING 70 mph on the edge of downtown St. Louis when the exploit began to take hold.

## Hackers can easily drain the battery on the world's most popular electric car



Paul Szoldra

Feb. 24, 2016, 3:42 PM +1,836



FACEBOOK



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The popular Nissan Leaf electric car can be drained of its battery life using little more than its vehicle identification number (VIN).

The major security hole was found by researcher Troy Hunt, who figured out that the Leaf's smartphone app interface (API) uses only the VIN to control car features remotely without passwords. These features include seeing the car's current battery life, times and distances the car has traveled, and





## But in reality they are all the same attack

1. Attacker finds exploit in physical or wireless systems
  - Most of these systems not designed to be secure gateways
  - Changed assumptions, e.g. “if inside the vehicle, authorized”
2. Exploit is used to gain access to the in-vehicle network
  - Which was not designed to host non-trusted entities, so
3. Message forgery or diagnostics actions can be leveraged
  - Vehicle theft
  - Temporary influence on vehicle operation
  - Permanent modification of vehicle
  - Extraction of personal information, tracking, etc.

# The defense circus is sometimes better than the offense circus!





## What is the systemic way out?

- The issue is that CAN is a trusted network
- Lots of research tries to address this, but reality is, changing this is **impractical**
- Lots of research tries to come up with magic IDSs, but we and others showed you can design attacks that simply **cannot be detected**
- Obviously, squashing bugs in **thousands** of combinations of ECUs and firmwares is pointless
- We can only approach this through **secure design** of networks based on **risk approaches**



## What is the systemic way out?

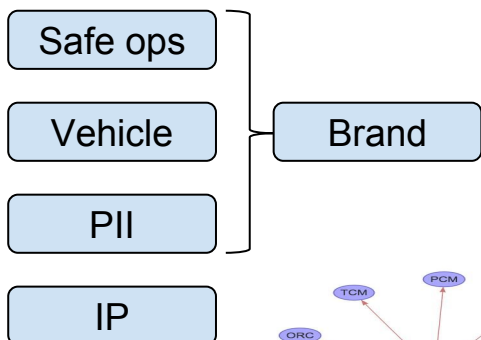
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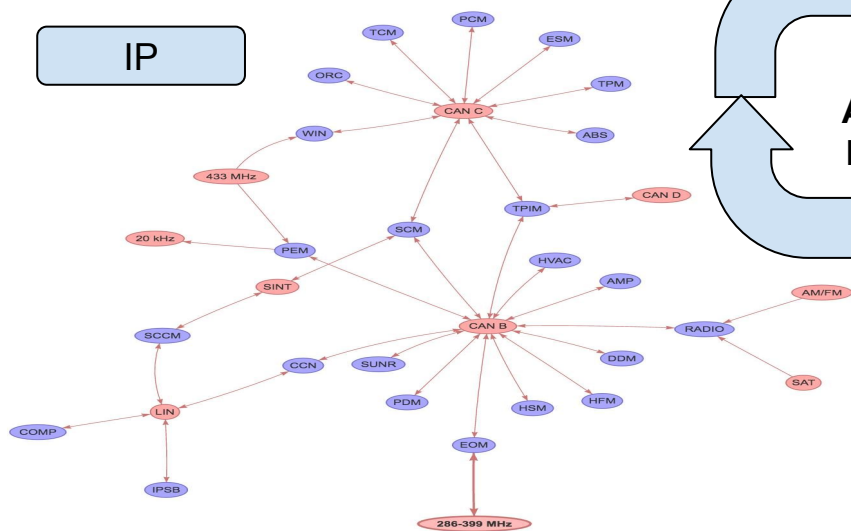
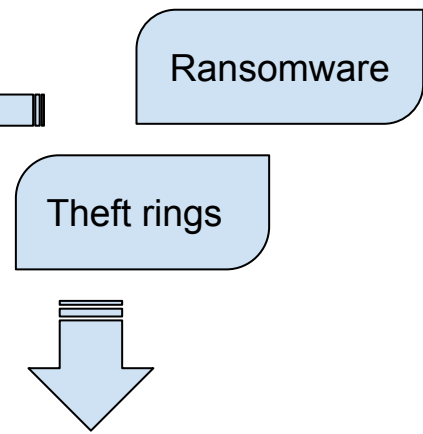


# An approach: risk-based design of networks (for automotive and more)

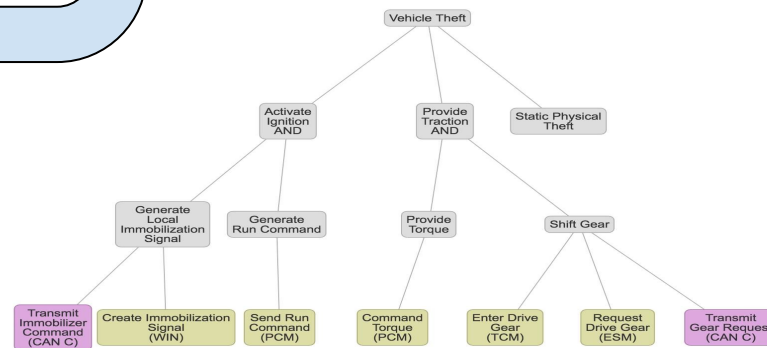
## Asset definition and value analysis



## Threat assessment and evaluation



Vehicle network topology mapping



Attack tree definition and analysis



- We focus way too much on attack research, vulnerability discovery and exploitation
- Vulnerabilities, in the grand scheme of things, do not really matter
- Stunt hacking distracts the industry and the public from actual sensible risk-based security
- We need more focus on:
  - Structural resilience
  - Architectural changes
  - Impact reduction



## Questions?

- Thank you for your attention!
- You can reach me at [stefano.zanero@polimi.it](mailto:stefano.zanero@polimi.it)
- Or just tweet [@raistolo](https://twitter.com/raistolo)

**Disclaimer: none of these materials, if posted without a video of the talk, should be construed to be a criticism of the specific research I used as examples.**

