Karlsruhe Institute of Technology

Resilient Networking

Disclaimer: this course has been created with very valuable input from Günter Schäfer, Mathias Fischer, and the members of the Chair

Module 1 – Preliminaries (Winter Term 2020)

Thorsten Strufe

Competence Center for Applied Security Technology

Lecture Outline

- Who are we?
- Organizational matters (preliminaries)
- Course outline

- A brief introduction

Who is Who

- Professur „IT Security and Privacy“
- For this lecture:
- Thorsten Strufe (Lectures)
  - 50.34/281
  - thorsten.strufe [at] kit.edu

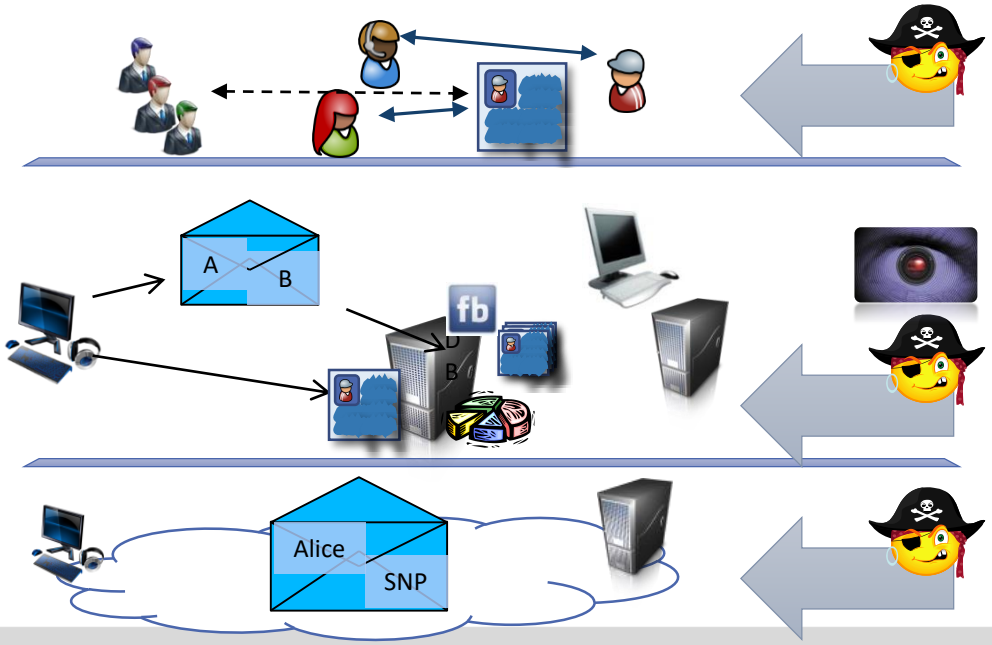
- Teaching assistants
- This lecture doesn‘t have one.

- Consultation:
- Send me an email (repeatedly…)

- https://ps.tm.kit.edu/

What we're working on…

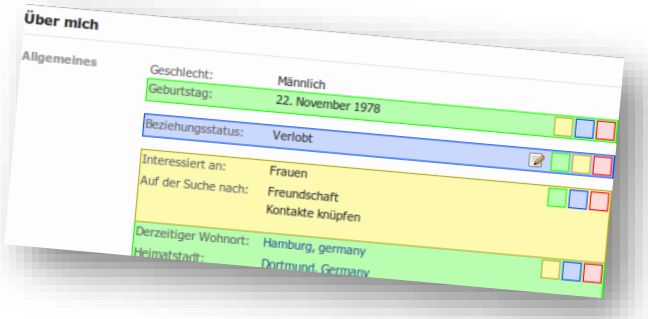
- ***User understanding***

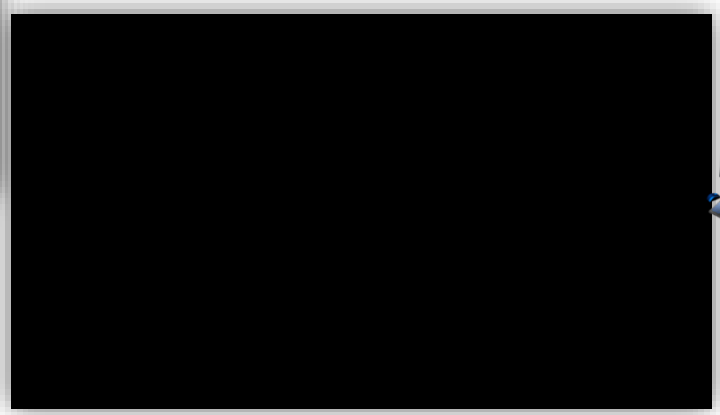


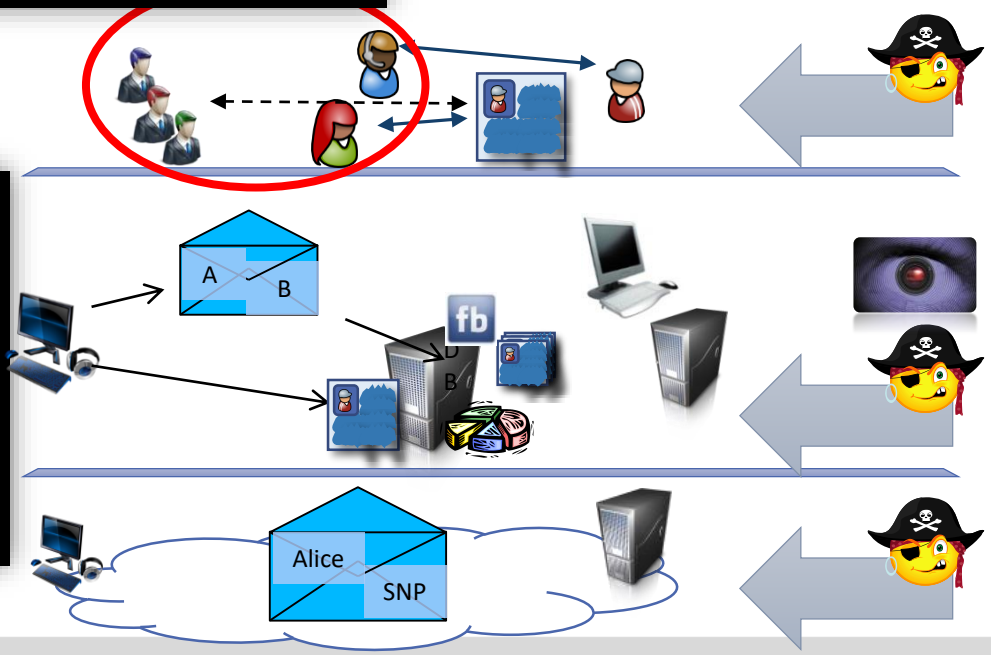
[7] FC '11
[8] WWW '12

What we're working on…

- ***User understanding***
  - Intention recognition
  - Privacy analyses
  - Data sanitation







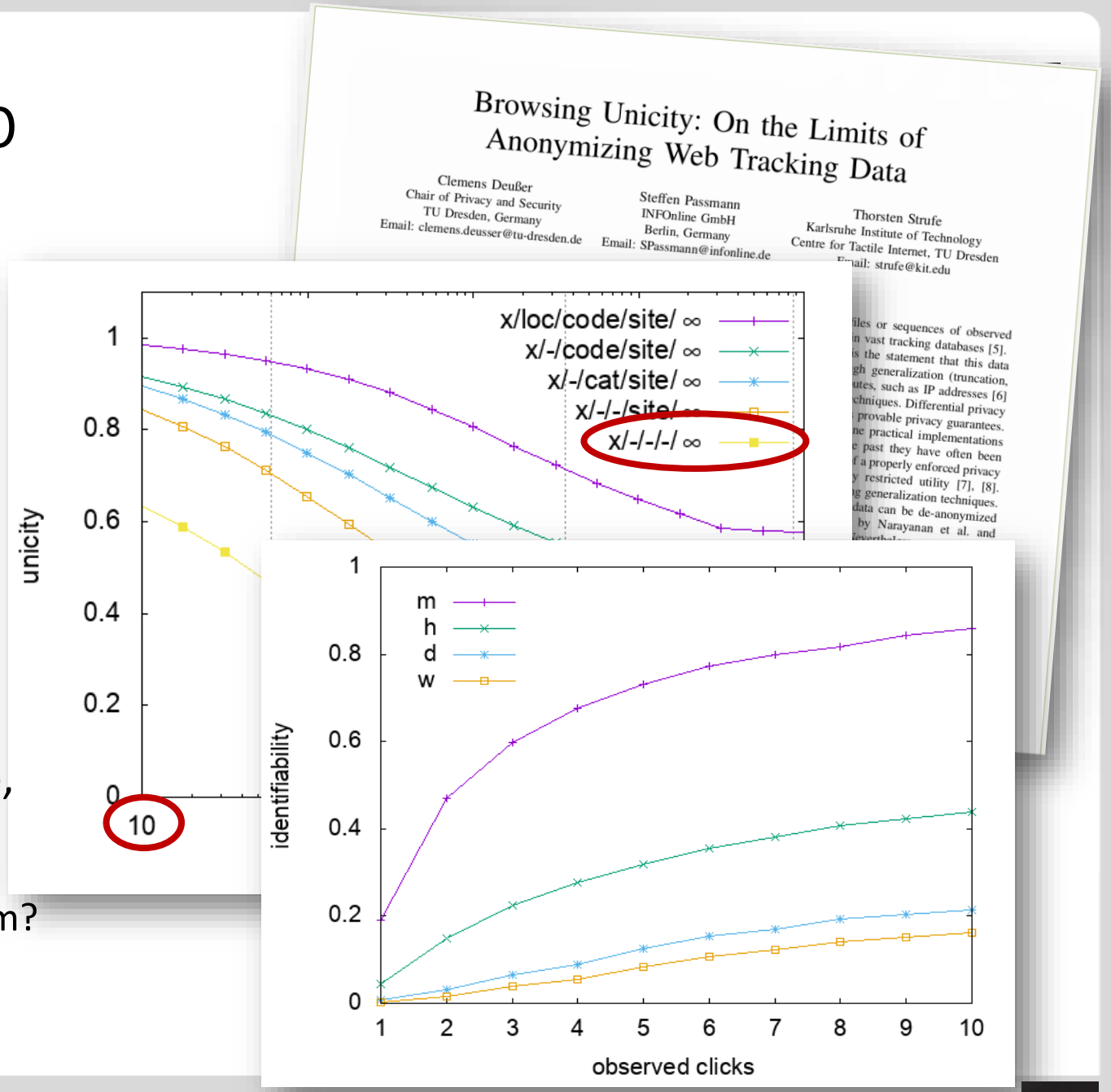
[7] FC '11
[8] WWW '12

Identifiability on the Web

- Web-Tracking is ubiquitous

- Situation:
  - Tracker claim anonymity
  - „delete last octett“: generalization
  - GDPR: Pseudonym ≠ Anonym

- Study
  - Cooperation with private partner
  - Comprehensive data set (German Web, 2-3 Bn visits per day)
  - Questions:
    - To which extent is behavior a pseudonym?
    - How little is needed to identify a trace?

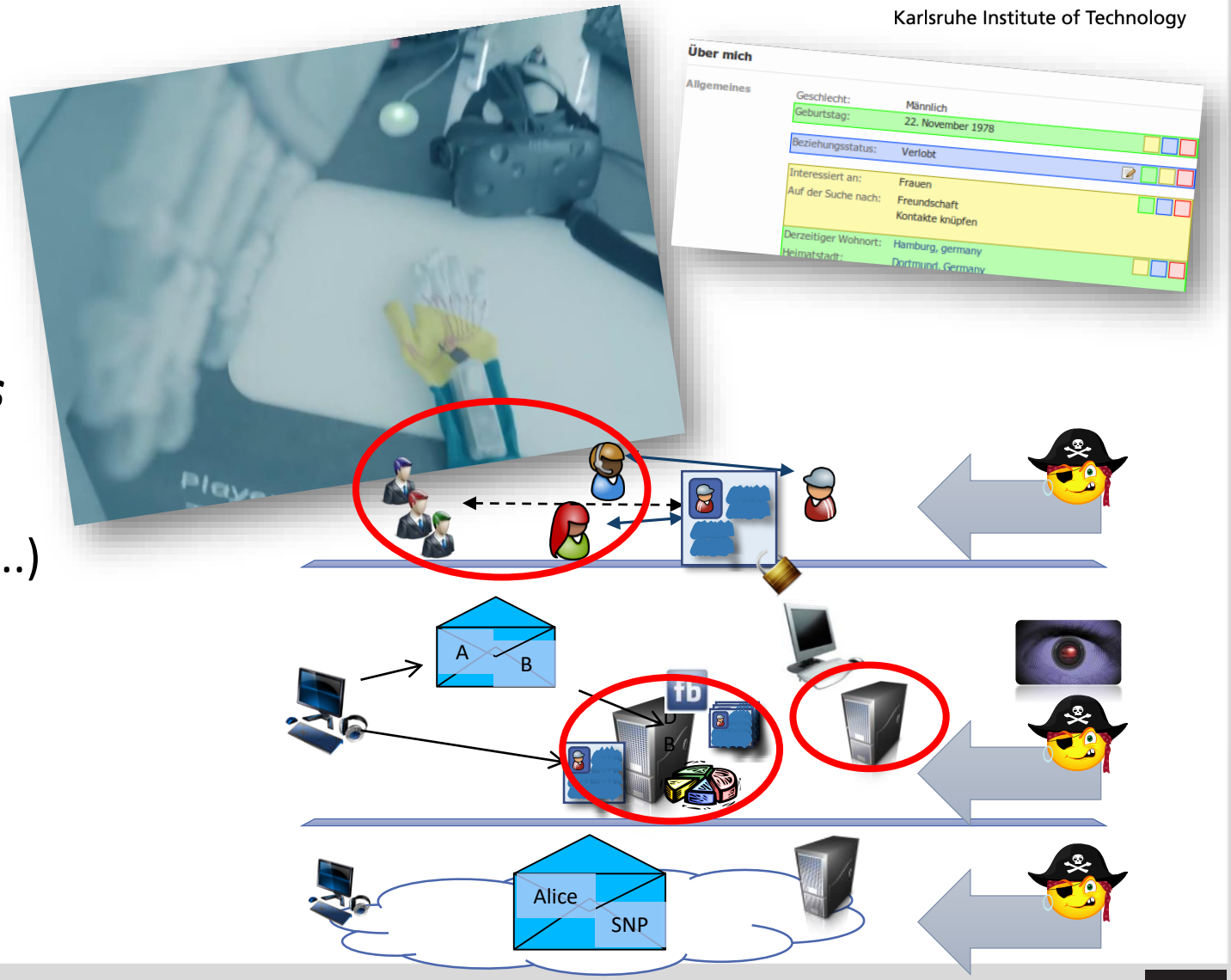


[9] IEEE S&P ’20

What we're working on…

- ***User understanding***
  - Intention recognition
  - Privacy analyses
  - Data sanitation

- ***Privacy-Enhancing Technologies***
  - Anonymity metrics
  - Anonymous services (f2f/Web)
  - Anonymous Communication (Tor, ..)



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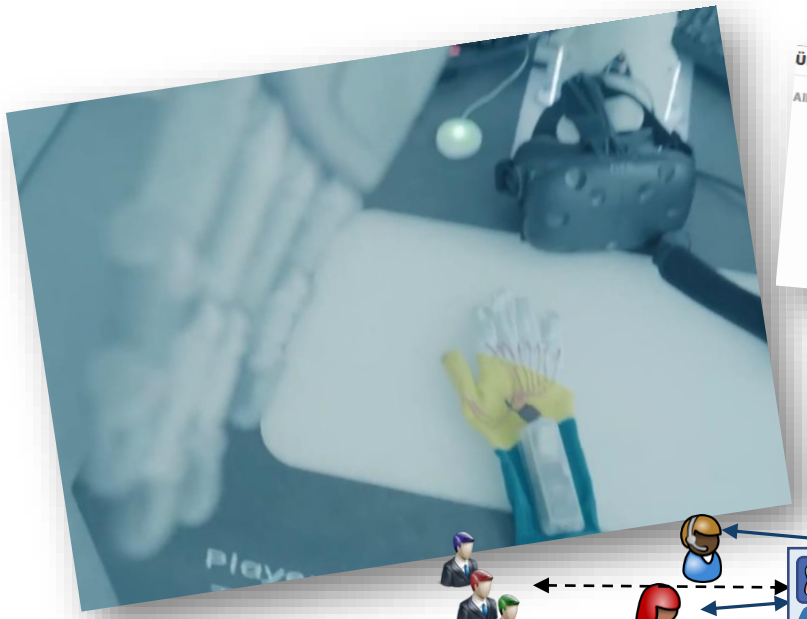
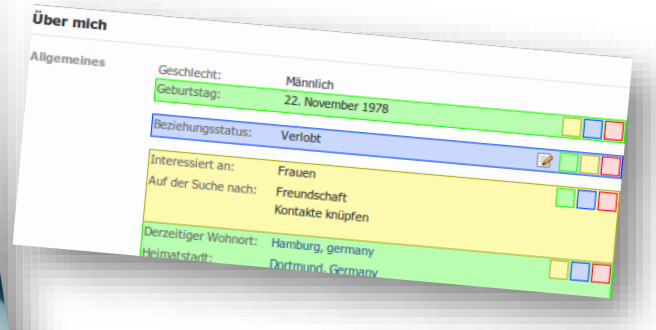
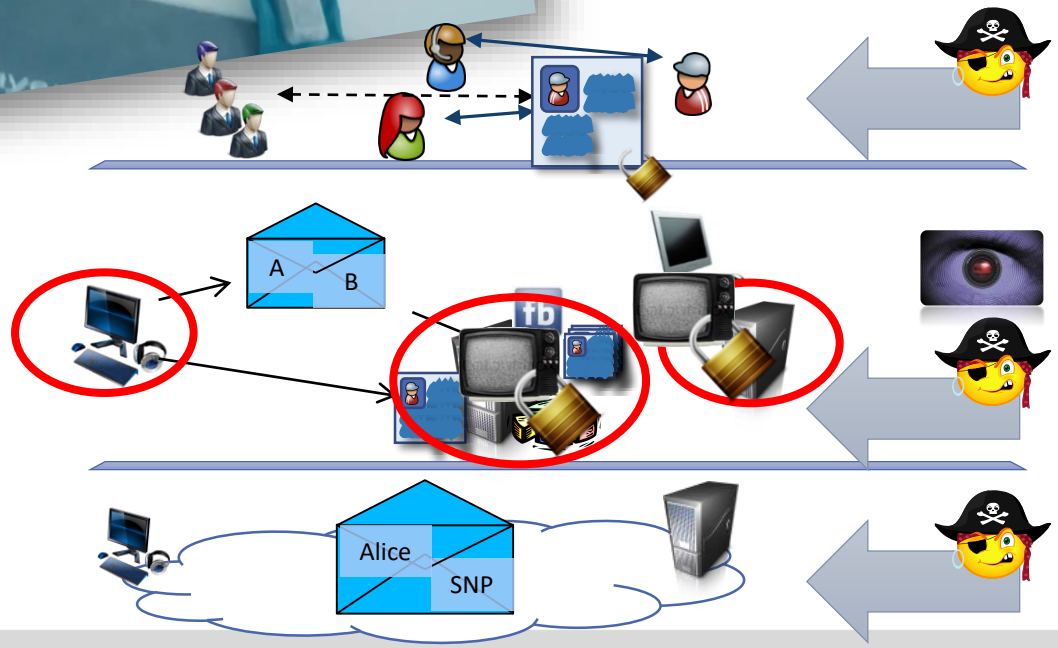


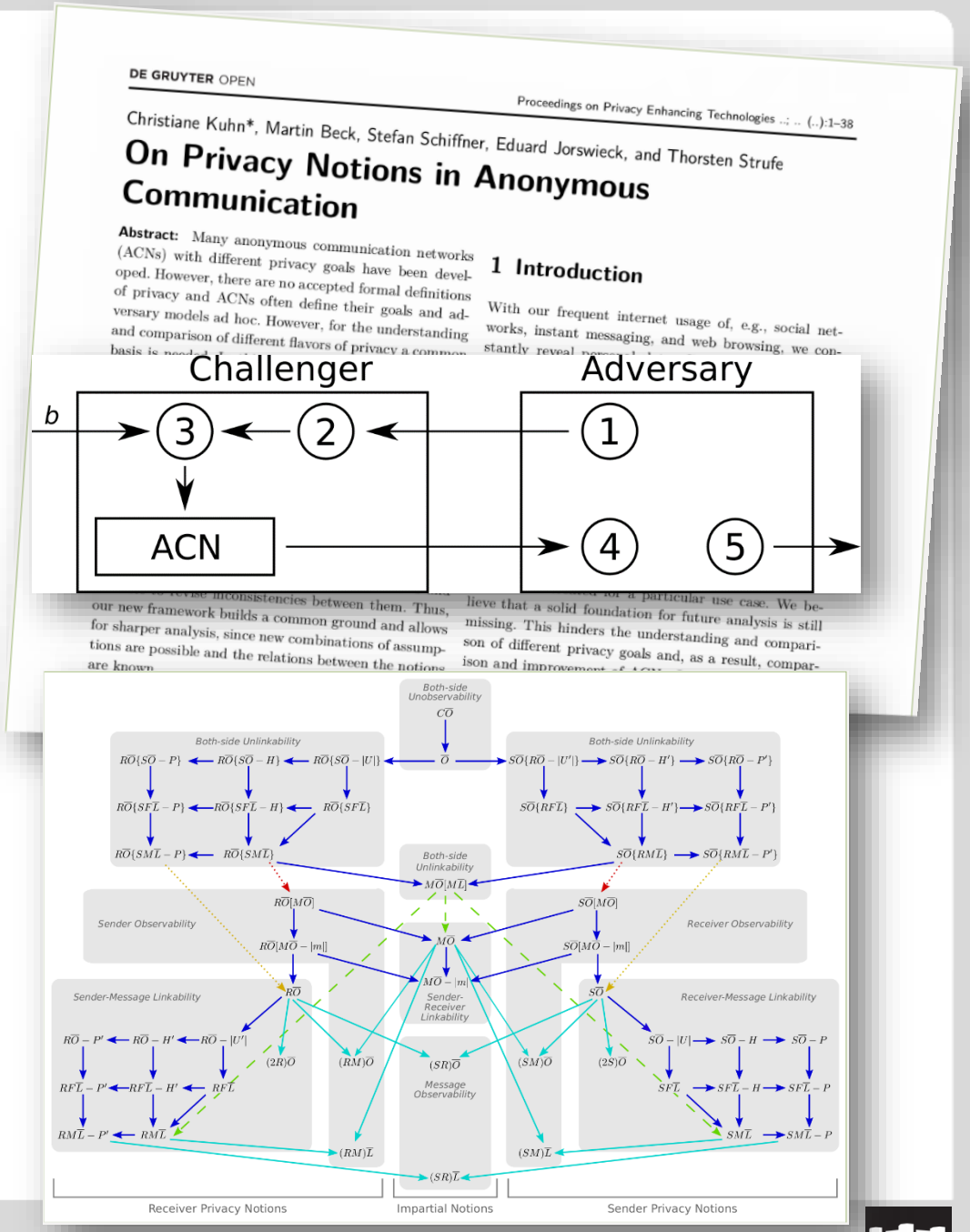




Anonymity Notions

- Plethora of anonymizers around
  - *TOR, AN.ON, DC, HORNET, Loopix, ZCash,…*
  - Claim *„Sender-Anonymity“*, or *„Recipient-Anonymity*, or *„Transaction Confidentiality“*
  - Literature defines *„Unlinkability“*, *„Unobservability“*, *„Pseudonymity“*, *„*-Anonymity“*, *„Anonymity Sets“*, *„Indistinguishability“*
  - So what does all this actually mean?

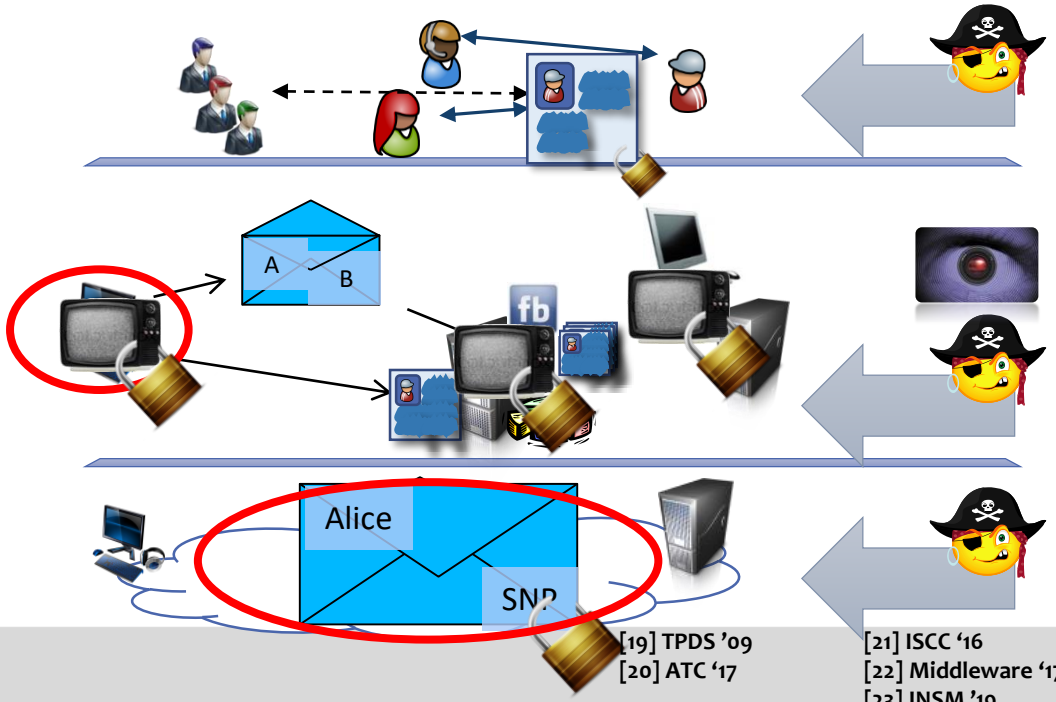
- Study
  - Game-based formalization of anonymity online
  - Consider all communication properties
  - Define and analyse privacy notions and their dependencies, rigorous protocol analysis



[17] PETS '19
[18] S&P '20

What we're working on

- ***User understanding***
  - Intention recognition
  - Privacy analyses
  - Data sanitation
- ***Privacy-Enhancing Technologies***
  - Anonymity metrics
  - Anonymous services (f2f/Web)
  - Anonymous Communication (Tor, ..)
- ***Network security***
  - SDN/NFV security
  - Isolation/VPNs
  - Denial-of-Service



[19] TPDS '09
[20] ATC '17
[21] ISCC '16
[22] Middleware '17
[23] INSM '19

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Resilient Networking

Lecture/Reading group Winter term 2020

Some Words Regarding this Course

- Main topic of the course is the *security of deployed, crucial networks, networking functions, and network protocols.*

- Considering the Internet: *networking is an essential service, hence the networking infrastructure is/may be the main target of attacks!*

- ***Now what!?***

Preliminary Course Overview

1. Introduction
2. Graphs and graph theory
3. Crypto basics (Symmetric/Asymmetric/MACs)
4. *Link-Layer Security*
5. Resilient Routing (Attacks on BGP, SBGP)
6. *IPsec*
7. *TLS*
8. DNS Security
9. DDoS and Countermeasures
10. *Resilient Overlay Networks / Blockchain / Darknets*
11. *Intrusion Detection and Response*

Organizational matters

- Lecture
- Tue 10:00 – 12:40 (hold up: Corona, so TUE 12-13:30 during this Winter term)
- Grashof lecture hall (hold up: Corona, so online, for now)

- Exercises
- Thu 10:00 – 11:30
- 50.34 301 (first meeting in CW 49: Dec 3, prepare *now;* Corona: online for now)

- Exams
- Oral exams, make appointments
- Procedure:
  - Questions available in German (and English upon request)
  - Answers given in German (and English upon request)

- All necessary information (will be) on the Web site

Organizational Matters

- There will be some ex-cathedra parts, but please ask and discuss as much as possible!

- Course Language
  - Slides are in English, presentation as you prefer
  - => What‘s your language of preference?

- Slide history
  - Based on several former courses given at TU Ilmenau, Uni Mannheim, TU Darmstadt, and Dresden
  - Heavily derived from „Network Security“ and „Protection of Communication Infrastructures“ of/with Prof. Schäfer in Ilmenau and extended with Prof. Fischer‘s input from UHH

Material

- Slides/recordings will be on the Web site

- Literature/References
- Schäfer, Roßberg: Network Security
- For crypto: Dan Boneh‘s coursera course

- David Kahn: The Codebreakers
- Simon Singh: The Code Book

The Reading Group (Exercises)

- Exercise course will be organized as a reading group
  - Papers (links) available on the webpage (soon)
  - Read papers early…
  - One paper with relation to lecture topics will be presented (by a random ***one*** of ***you***!) and discussed (by ***you***!) each week (please take note of the emphasize on ***YOU :-)***)

Questions?

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Developing our terms…

Motivation: A Changing World

Let's get started!

- "Always on", ubiquitous connectivity to the global Internet has dramatically changed the way we
  - communicate,
  - conduct business, and
  - organize our society
- CPS, connected cars, and pervasive computing promise to create an additional layer of networked devices
- However, the benefits associated with information and communication technology imply new vulnerabilities

➡ The modern information society exhibits an increasing dependence on ***availability*** and ***secure operation*** of ***communication services***

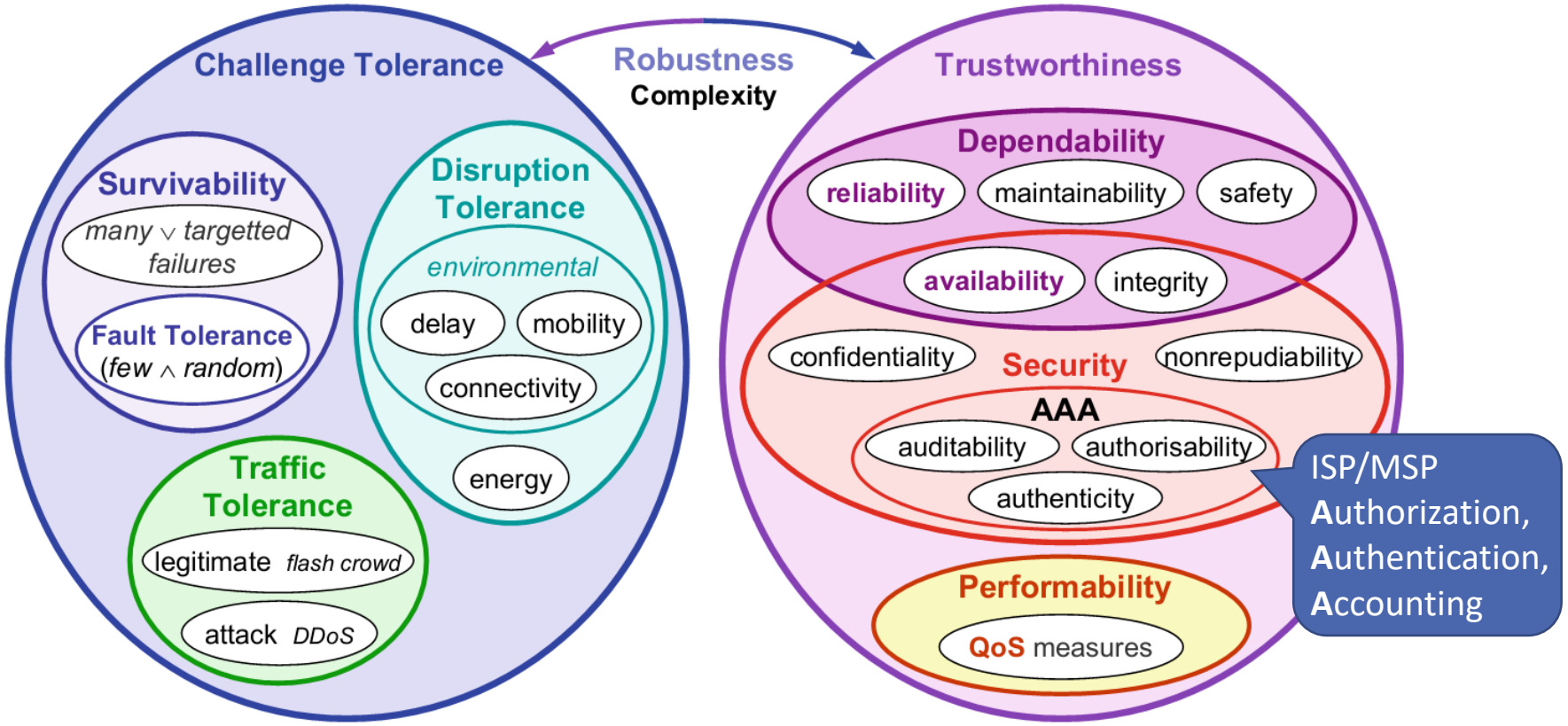
What are „Resilient Networks“?

- *“Resilience is the ability of an object to spring back into shape”*
- *“Resilience is the ability of the network to provide and maintain an adequate level of service in the face of challenges to normal operation”*
- *“Resilience is the ability of the network to provide and maintain an acceptable level of security service in case some nodes are compromised.”*
- Challenges? Compromised nodes…?
- What kind of *problems, challenges, threats* could you imagine?
- What ***exactly*** do these terms mean, anyway?

Sterbenz: Resilinets, 2006-2008
Chen et al.: Sensor Network Security, 2009

Resilience Disciplines

Resilience comprises a multitude of disciplines

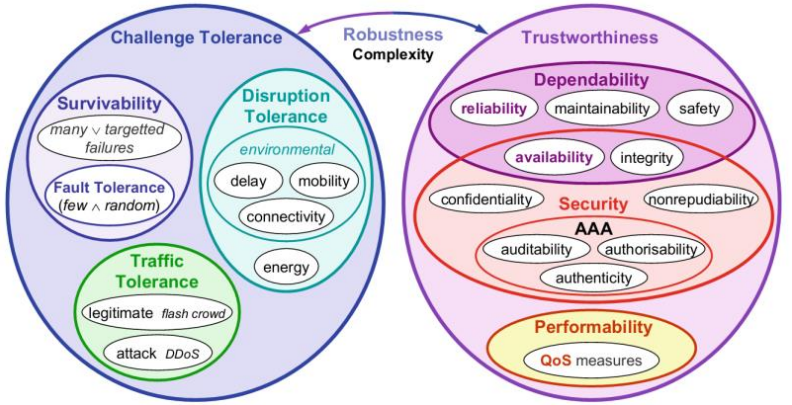


Sterbenz, James P.G., Hutchison, David, Çetinkaya, Egemen K Jabbar, Abdul, Rohrer, Justin P, Schöller, Marcus and Smith, Paul. Resilience and survivability in communication networks: Strategies, principles, and survey of disciplines. IEEE Computer Networks, 2010

Resilience – Challenge Tolerance (1)

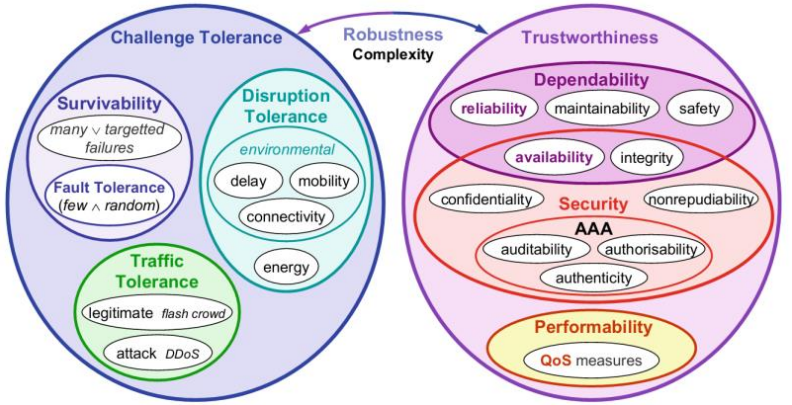
- ***Survivability***
  - Capability of a system to fulfill its mission,
    - in a timely manner,
    - in the presence of ***threats*** such as ***attacks*** or large-scale natural ***disasters.***
  - Covers ***correlated failures*** as result of ***intelligent adversary*** and failures of large parts of network infrastructure
  - Requires **diversity**: same fate unlikely to be shared by parts of system undergoing correlated failures

- ***Fault tolerance***
  - Subset of survivability
  - Ability of system to tolerate faults to ***prevent service failures***
  - Relies on **redundancy** to compensate random uncorrelated failures of components
  - Provides no sufficient coverage when facing correlated failures



Resilience – Trustworthiness (1)

- ***Dependability***
  - Quantifies resilience of the service delivery by a system
  - Basic measures
    - Mean Time To Failure (MTTF)
    - Mean Time To Repair (MTTR)
  - Consists of
    - ***Availability***: readiness for usage
    - ***Reliability***: continuous service delivery



- ***Security***
  - Property of a system, and the measures taken such that it protects itself from ***unauthorized access or change***
  - Security shares availability with dependability
  - However, we assume a strategic adversary (worst case, repeatedly…)

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The Security in Resilience…

Security Goals in Application Environments

- Public Telecommunication Providers:
  - Protect subscribers' privacy
  - Restrict access to administrative functions to authorized personnel
  - Protect against service interruptions
- Corporate / Private Networks:
  - Protect corporate confidentiality / individual privacy
  - Ensure message authenticity
  - Protect against service interruptions
- All Networks:
  - Prevent outside penetrations (who wants hackers?)
- Security goals are also called ***security objectives***

Security Goals Technically Defined (CIA)

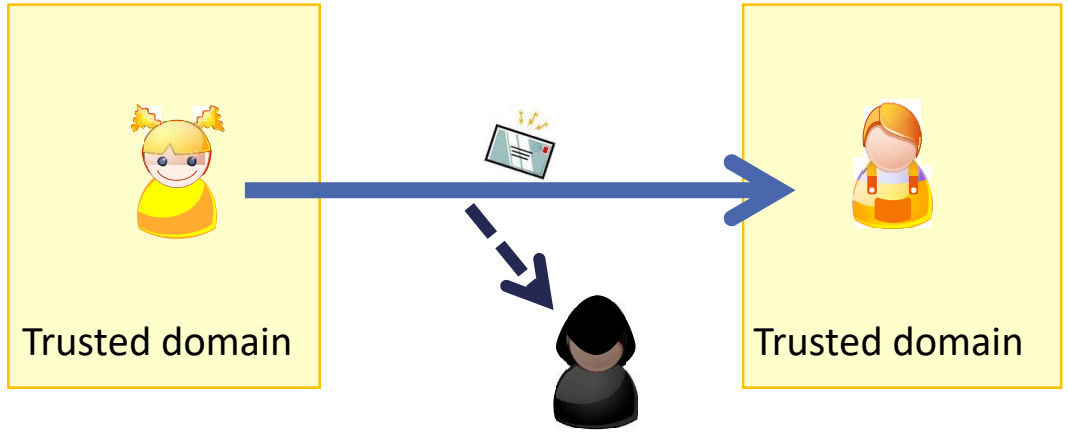
- ***C**onfidentiality:*
  - Data transmitted or stored should only be revealed to the intended audience
  - ***Confidentiality of entities*** is also referred to as ***anonymity***
- *(Data) **I**ntegrity:*
  - It should be possible to detect any modification of data
  - This requires to be able to *identify* the creator of some data
- ***A**vailability:*
  - Services should be available and function correctly

- *Accountability:*
  - *It should be possible to identify the entity responsible for any communication event*
- *Controlled Access:*
  - *Only authorized entities should be able to access certain services or information*

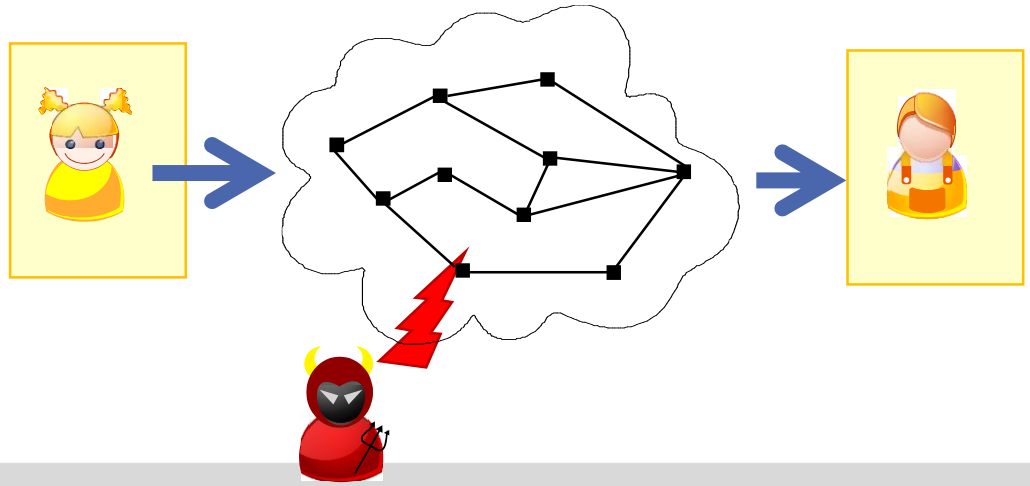
Several other models have been proposed, anything beyond CIA is constantly subject to arguments and discussions…

Introducing Actors of the Play

- For clarity it‘s good to have some model…
- The classic security – scenario:



- The RN – scenario:

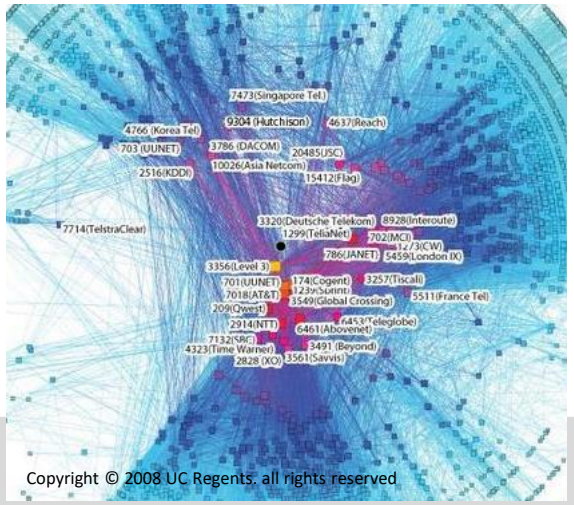


Threats in Communication Networks

- Abstract Definition:
  - A threat is any possible event or sequence of actions that might lead to a violation of one or more security goals
  - The actual realization of a threat is called an ***attack***

- Examples:
  - A hacker breaking into a corporate computer
  - Disclosure of emails in transit
  - A hacker temporarily shutting down a website
  - Someone using services or ordering goods

    in the name of others
  - ...

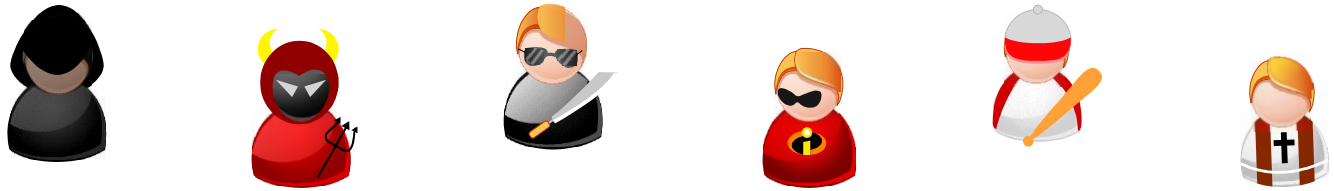


Potential Attackers and an Adversary Model

A word on assumptions.

- Assume an omnipotent adversary. She could:
- access all information of interest
- compromise arbitrary intermediate systems
- physically destroy any or all components

- Could we deal with this?
- Unfortunately, no:
- *„Nothing can protect from an omnipotent adversary.“*



- More realistic (specific!) model of adversaries needed.

On Eve, Mallory, Craig, and Trudy…

- An ***adversary model*** needs to define
- The *intention* of the adversary
  - Break and/or access <something>
- The *behavior*
  - Passive or active?
- The *capabilities* of an attacker
  - Computational capacity (often: think complexity class)
  - Resources (time and money)
- The *area of control*
  - Insider or outsider?
  - Local, regional, or global?

The Dolev - Yao Model

- Mallory has full control over the communication channel
  - Intercept/eavesdrop on messages (passive)
  - Relay messages
  - Suppress message delivery
  - Replay messages
  - Manipulate messages
  - Exchange messages
  - Forge messages

- But:
  - Mallory ***can't*** break (secure) cryptographic primitives!

Threats Technically Defined

- *Masquerade:*
  - An entity claims to be another entity
- *Eavesdropping:*
  - An entity reads information it is not intended to read
- *Authorization violation:*
  - An entity uses a service or resources it is not intended to use
- *Loss or Modification of (transmitted) information:*
  - Data is being altered or destroyed
- *Denial of Communication Acts (Repudiation):*
  - An entity falsely denies its participation in a communication act
- *Forgery of information:*
  - An entity creates new information in the name of another entity
- *Sabotage:*
  - Any action that aims to reduce the availability and / or correct functioning of services or systems

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That was fairly abstract…

How can we operationalize this?

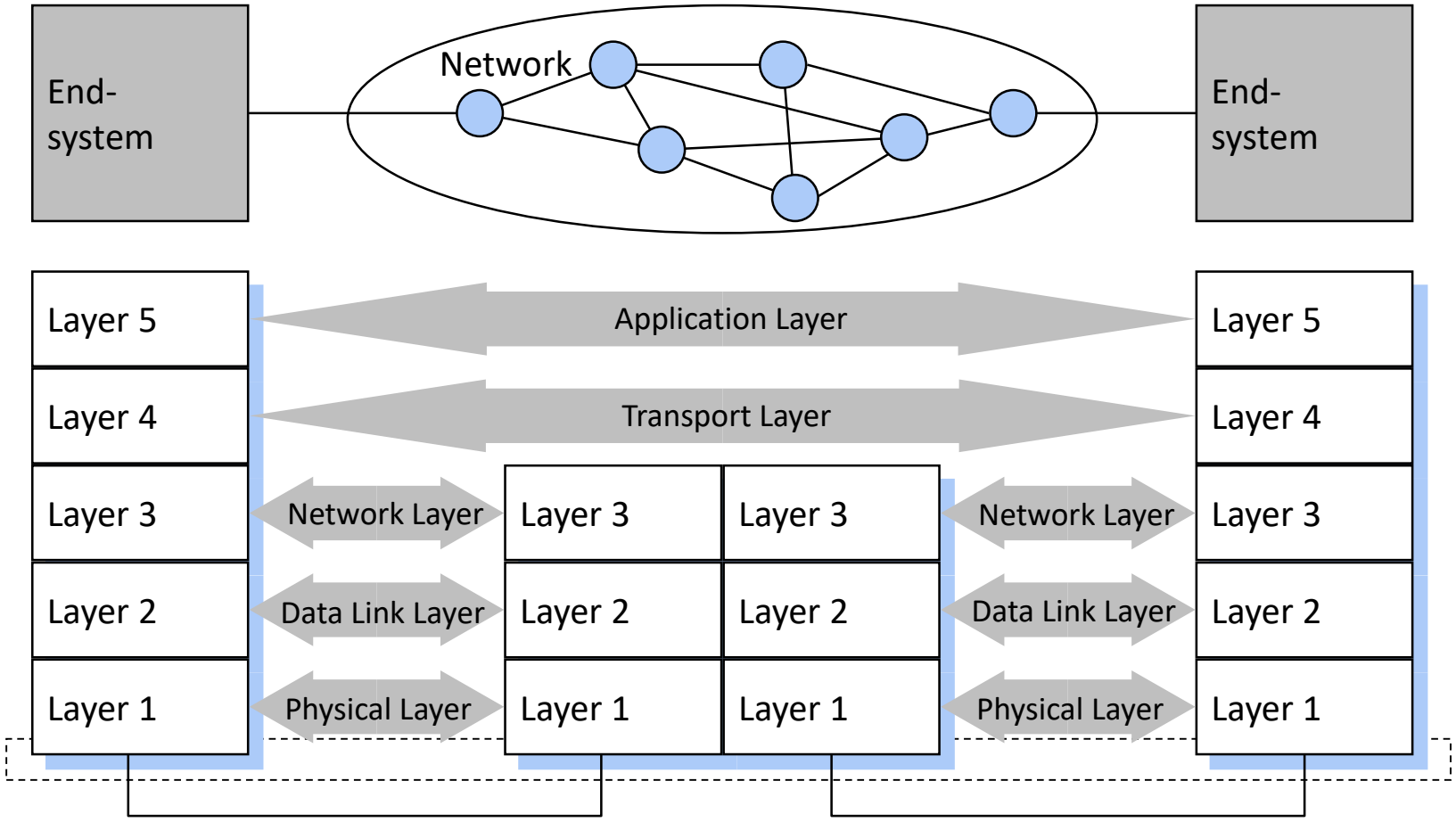
Network Security Analysis

- To find countermeasures, threats have to be evaluated appropriately for a given network configuration.

- Therefore, a detailed network security analysis is needed that:
  - evaluates the ***risk potential*** of the general threats to the entities using a network, and
  - estimates the ***expenditure*** (resources, time, etc.) needed to perform known attacks.

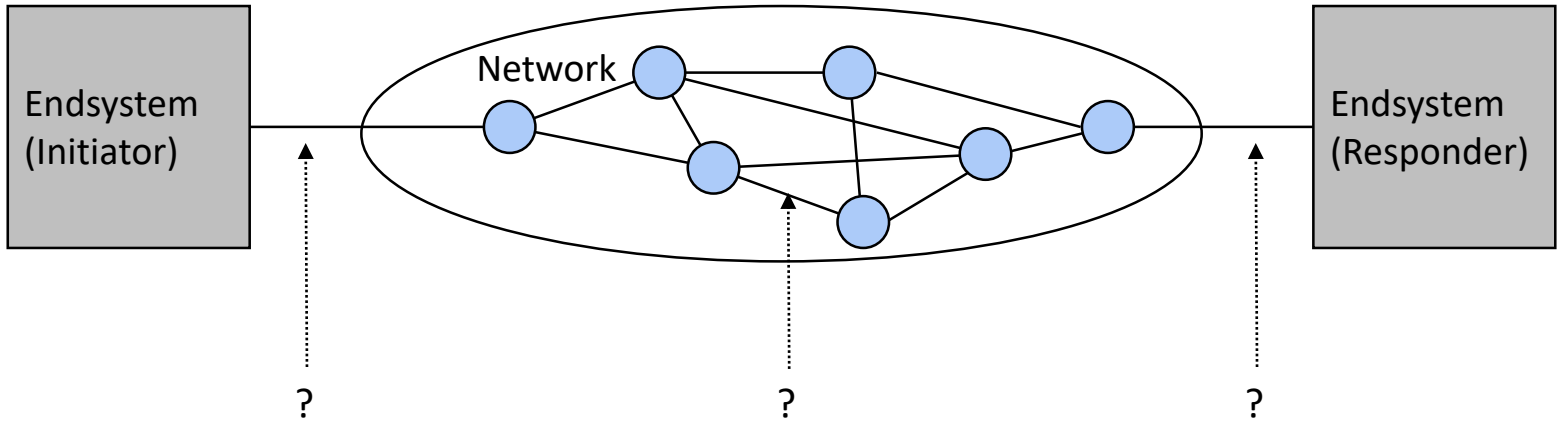
→ Attention: *It is generally impossible to assess unknown attacks!*

Architectural View of the Threatened “Object”



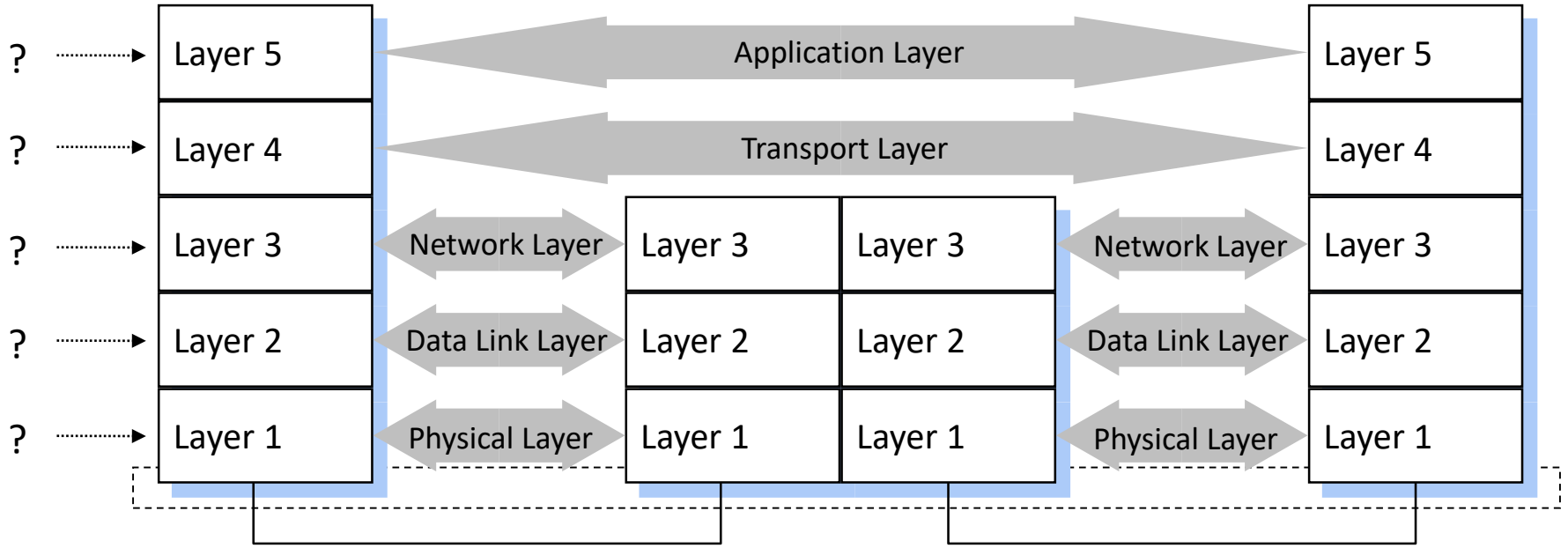
Communication in Layered Protocol Architectures

Security Analysis of Layered Protocol Architectures 1



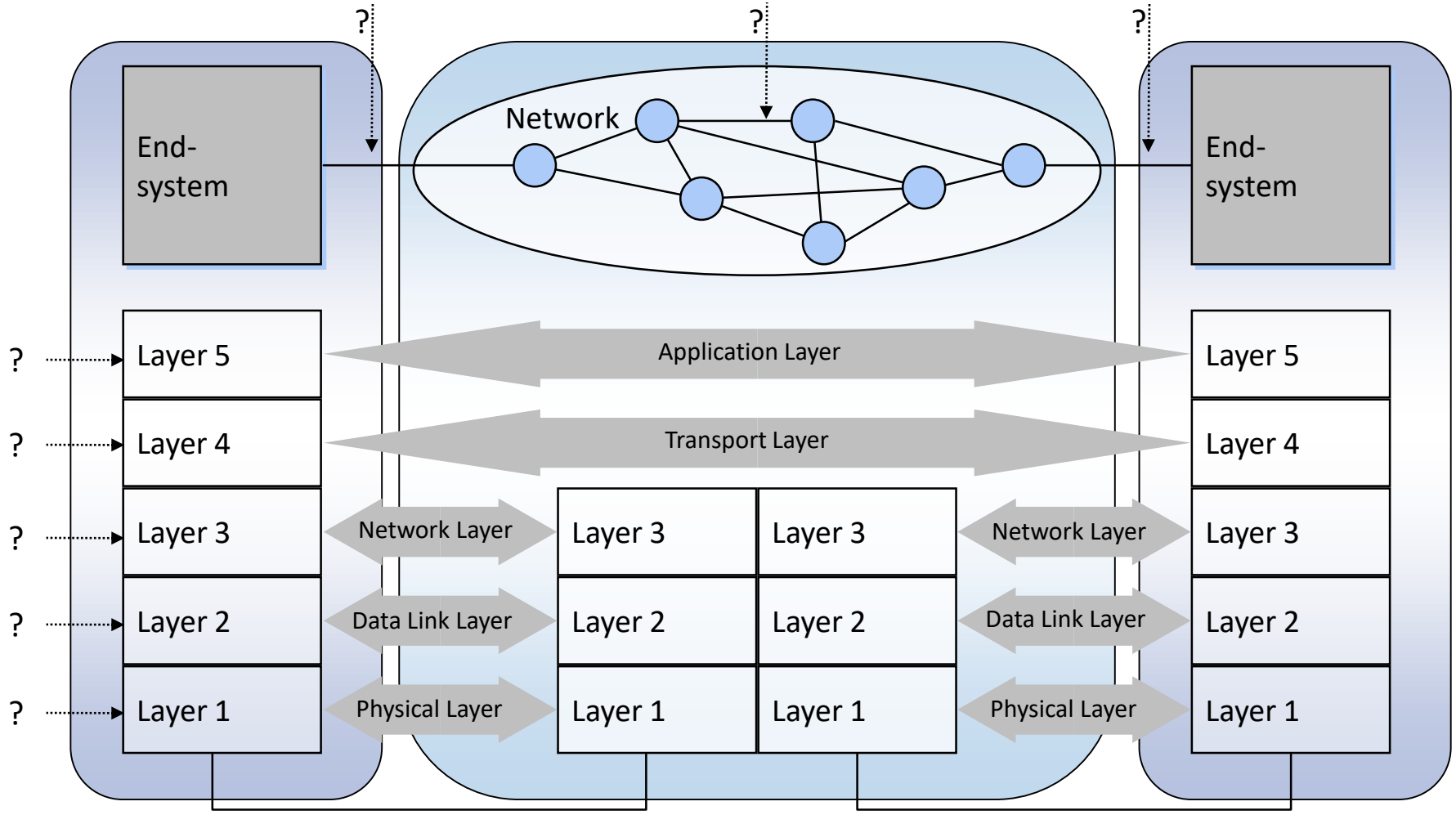
Dimension 1: At which interface could an attack take place?

Security Analysis of Layered Protocol Architectures 2



Dimension 2: In which layer could an attack take place?

Potential Points of Attack



Towards a Systematic Threat Analysis

- One approach: produce arbitrary threat list by any ad-hoc brainstorming method

- Example: Hospital Information System
  - Corruption of patient medical information
  - Corruption of billing information
  - Disclosure of confidential patient information
  - Compromise of internal schedules
  - Unavailability of confidential patient information
  - …

Downside: not very systematic…

- Drawbacks of this approach:
  - Questionable completeness of identified threats
  - Lack of rationale for identified threats other than experience
  - Potential inconsistencies (e.g. disclosure vs. unavailability of confidential patient information in the example above)

Approaches for Systematic Threat Modeling

- Explicit quantification of security is hard (impossible?)
- Threat modelling is a soft task

- Alternative management approaches have been suggested
  - STRIDE
    - Risk identification (Microsoft: Kohnfelder and Garg, 1999)
    - ***S**poofing, **T**ampering, **R**epudiation, **I**nformation-disclosure, **D**oS, **E**levation of Privilege*
  - DREAD
    - Risk assessment, as used e.g. by OpenStack (among others)
    - ***D**amage, **R**eproducibility, **E**xploitability, **A**ffected Users, **D**iscoverability*
  - Threat Trees (Amoroso, 1994) (later on: „Attack trees“)

Shostak: “Experiences Threat Modeling at Microsoft”, 2004

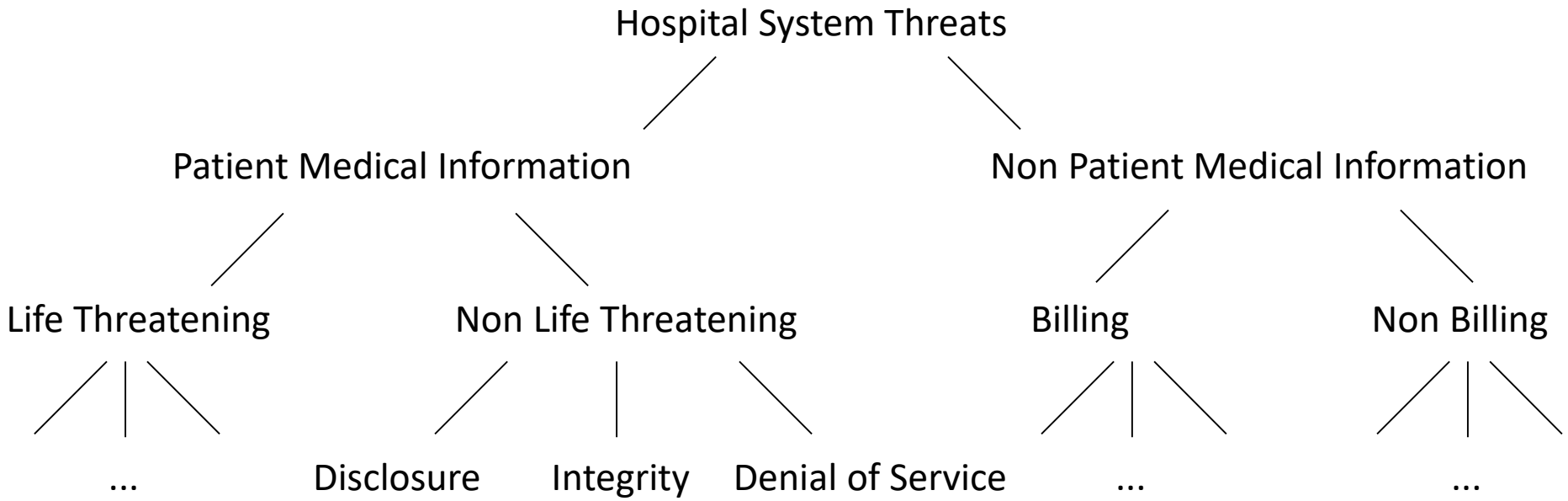
Threat Trees: One Systematic Threat Analysis Approach

- A *threat tree* is a tree with:
  - *nodes* describing threats at different levels of abstractions, and
  - *subtrees* refining the threat of the node they are rooted at,
  - where the child nodes of one node give a *complete refinement* of the threat represented by the parent node

- Technique for establishing threat trees:
  - ***Start*** with general, abstract description of complete set of threats for a given system (e.g. “security of system X compromised”)
  - ***Iteratively***, gradually introduce detail by carefully refining the description
  - Each node becomes root of a ***subtree*** describing ***threats*** represented by it
  - Eventually, each ***leaf node*** of the tree provides a description of a threat that can be used for a (less arbitrary) threat list

- The main idea of this technique is to postpone the creation of (arbitrary) threat lists as much as possible

Example: A Hospital Information System Threat Tree

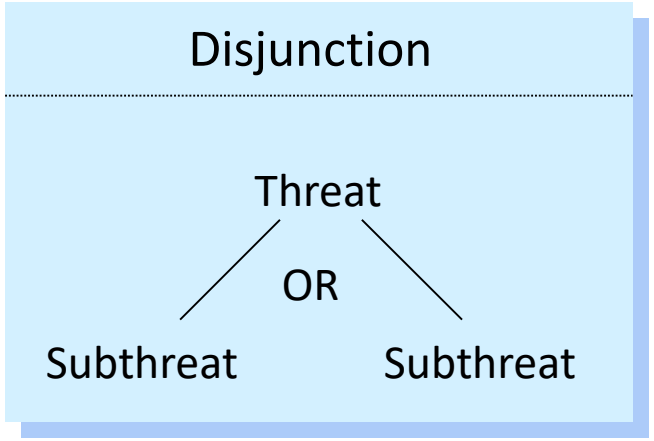


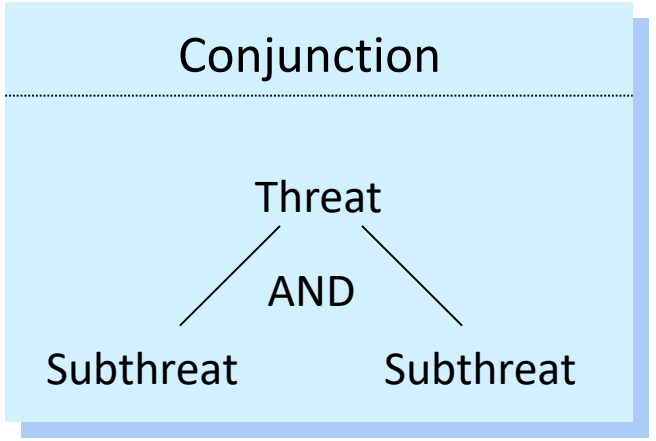
➡ At each level of refinement the child nodes of a node ***must*** maintain *demonstrable completeness* to allow for confidence that nothing is missing

(source: [Amo94])

Inferring Composed Threat in Threat Trees

- Child nodes can have different relations to their parent nodes
- The two most common relations are AND and OR:

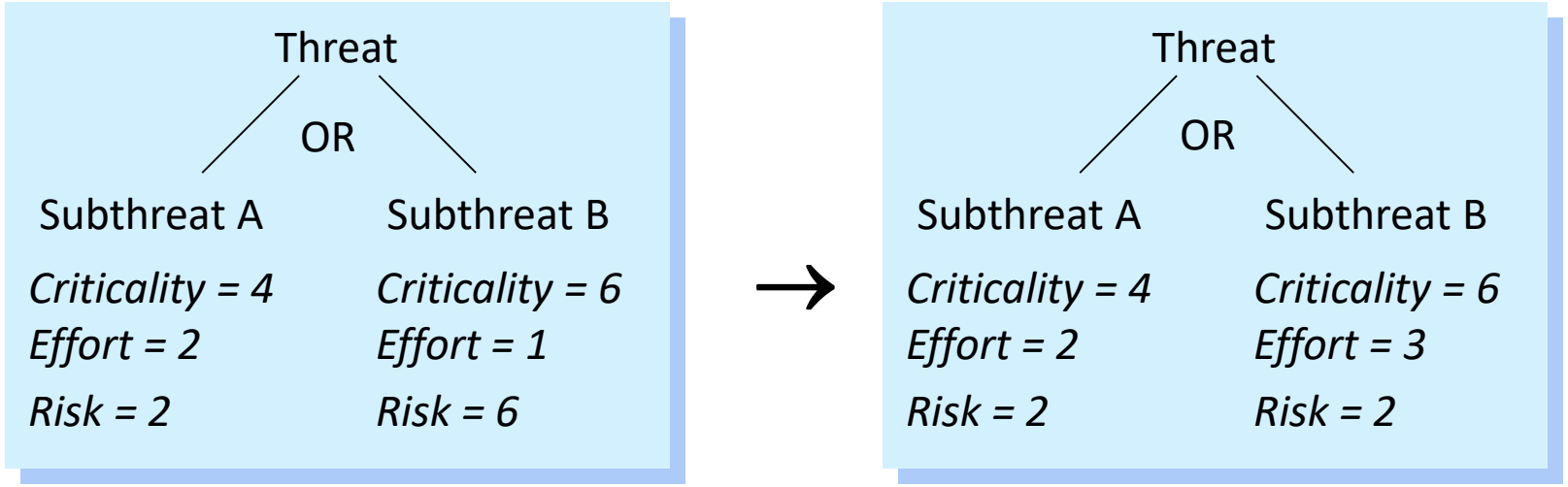




- These relations can be used to infer composed threat:
  - Augment nodes with effort estimations (e.g. easy, moderate, high)
  - OR-related composed threat inferred as the lowest effort value subtree (the attacker will most likely take the easy way...)
  - For conjunction, infer highest effort (all threats have to be realized)

Risk-Assessment/Quantification with Threat Trees

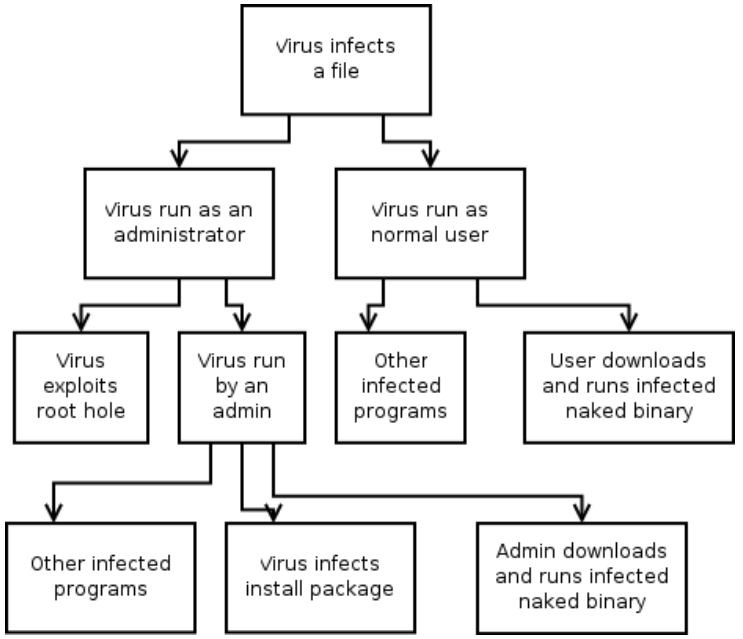
- Appropriate attributes are, e.g., estimated criticality and attacker effort for individual threats
- Threat trees then can help to gain insight where to spend resources to decrease the overall system's vulnerability:



- The second threat tree re-evaluates the risk after some protective measure has been taken to increase the attacker's effort for subthreat B
- Here, risk is assessed as: ***Risk = Criticality / Effort***

Variation of the Game: Attack Trees

- NSA/Darpa/Schneier‘s approach:
  - Model the attacker‘s goal as root node
  - Branches model means of reaching the goal
  - Leaf nodes enumerate specific attacks



Source: wikipedia

Summary (High Level System Security Engineering Process)

- Specify system architecture:
  - Identify components and interrelations
- ***Identify threats***, vulnerabilities and attack techniques:
  - The threat tree technique provides help for this step
- ***Estimate*** component ***risks*** by adding attributes to the threat tree:
  - However, removing subjectivity from initial assessments is often impossible and other attributes than criticality and effort (e.g. risk of detection) might have to be considered as well
- Prioritize ***vulnerabilities***:
  - Taking into account the components' importance
- Identify and install ***safeguards***:
  - Apply protection techniques to counter high priority vulnerabilities
- Perform potential ***iterations*** of this process
  - Re-assess risks of the modified system and decide, if more iterations are required

Countering Attacks: Three Action Classes

- ***Prevention**:*
  - Measures taken to avert that an attacker succeeds in realizing a threat
  - Examples:
    - *Cryptography*: encryption, computation of modification detection codes, running authentication protocols, etc.
    - *Firewalls*: packet filtering, service proxying, etc.
- ***Detection**:*
  - Measures taken to recognize an attack *while or after it occurred*
  - Examples:
    - Recording and analysis of audit trails
    - On-the-fly traffic monitoring
- ***Reaction**:*
  - Measures taken in order react to *ongoing (mitigation and healing) or past attacks*
  - *Examples:*
    - *Adding new firewall rules*
    - *Traffic re-routing*
- *(DDS: Prevention, Removal, Forecasting, Tolerance/Graceful degradation)*

Course Objectives

- This course tackles the following aspects:
  - Threats to and measures for ensuring ***availability***
  - Threats and measures concerning systems (beyond pure network security protocols which are more targeting transmission security)
  - Measures for intrusion detection and response

- *Considering the Internet: networking is an essential service, hence the networking infrastructure is/may be the main target of attacks! We'll hence be looking at the security of deployed, crucial networks, networking functions, and network protocols.*

Summary

- You know who we are
- You know what to expect from the lecture
- You have seen some trends that are happening
- You have been introduced to Alice, Bob, Eve, and Mallory
- You understand what threats are … and what this means
- You can tell security goals (*CIA!*) from security services
- You know how to perform a network security analysis using threat trees ;-)

Papers we want to read:

- Réka Albert, Hawoong Jeong & Albert-László Barabási: *„Error and attack tolerance of complex networks“*, Nature
- Magoni, Damien. *"Tearing down the Internet."* IEEE Journal on Selected Areas in Communications 21.6 (2003): 949-960
- Schuchard, Max, et al. "Losing control of the internet: using the data plane to attack the control plane." Proceedings of the 17th ACM conference on Computer and communications security. ACM, 2010.
- "All your dns records point to us: Understanding the security threats of dangling dns records." Proceedings of the 2016 ACM SIGSAC Conference on Computer and Communications Security. ACM, 2016.
- Rossow, Christian. "Amplification Hell: Revisiting Network Protocols for DDoS Abuse." NDSS. 2014.
- -- "Identifying the scan and attack infrastructures behind amplification DDoS attacks." Proceedings of the 2016 ACM SIGSAC Conference on Computer and Communications Security. ACM, 2016.

Questions?