Advanced Networking: Introduction

Geert Heijenk, Pieter-Tjerk de Boer, Roland van Rijswijk-Deij, Nathan Djojomoenawie, Cristian Hesselman

University of Twente | September 6, 2023

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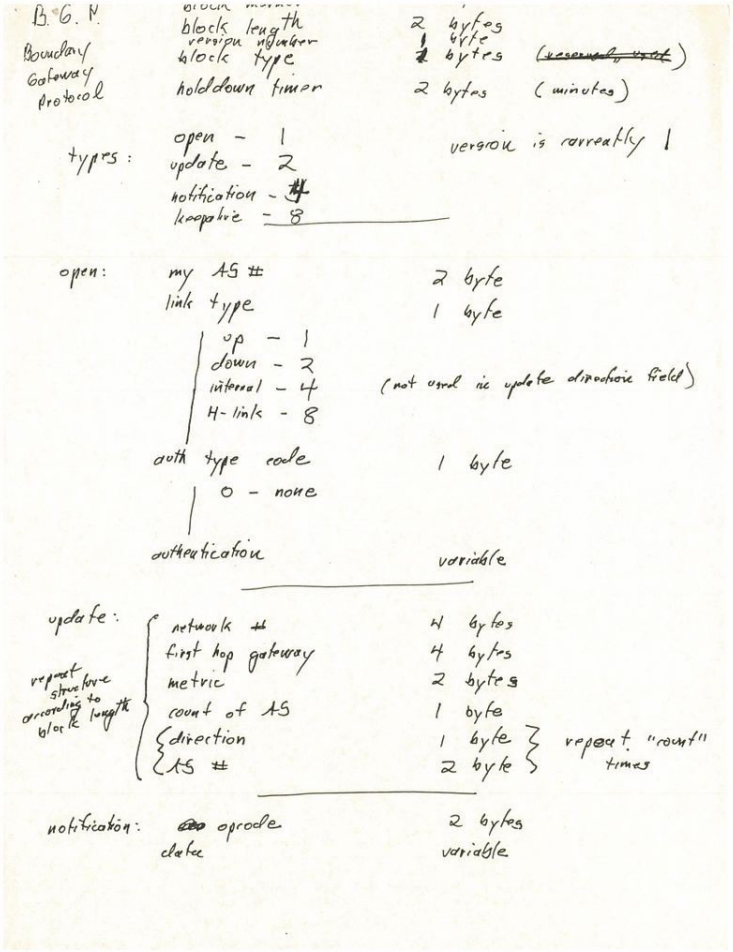
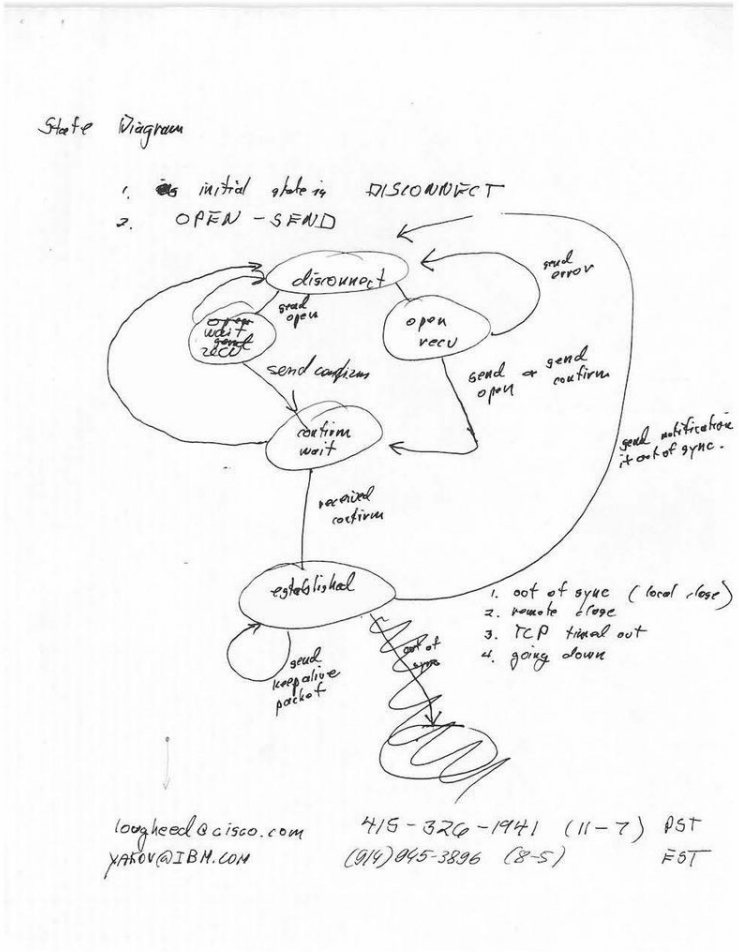
Advanced networking in 1989 :-)





https://computerhistory.org/blog/the-two-napkin-protocol/

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Your teaching team

Geert Heijenk
(teacher)

Pieter-Tjerk de Boer
(teacher)

Roland van Rijswijk-Deij
(teacher)

Nathan Djojomoenawie
(teaching assistant)

Cristian Hesselman
(teacher and coordinator)

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Today's learning objective

- Guide you through what we expect from you and why, and what you can expect from us
- Get you even more excited about internetworking :-)

- Answer questions you may have on assessment, deliverables, etc.
- Full details on the ANET site at https://courses.sidnlabs.nl/anet/

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Agenda

- High-level introduction to how the Internet works (and a bit of history)
- Course overview (admin talk)
- Short overview of the P4 lab assignment (Nathan)
- Q&A

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How the Internet works

(from a 50,000-foot perspective)

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What is the Internet?

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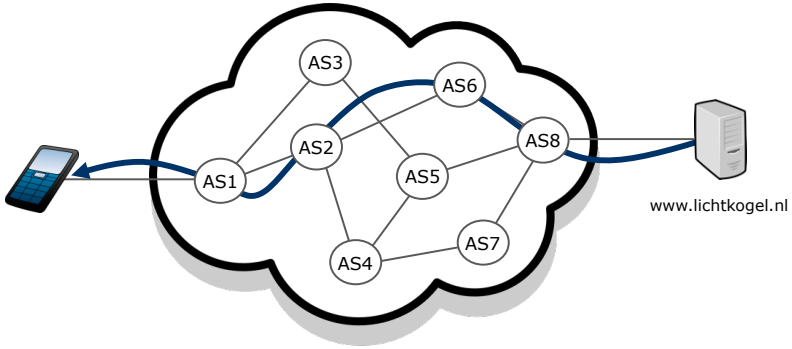
Wikipedia: networks of networks

- Internet: “the global system of interconnected computer networks that use the Internet protocol suite (TCP/IP) to link devices worldwide. It is a **network of networks** that consists of private, public, academic, business, and government networks of local to global scope, linked by a broad array of electronic, wireless, and optical networking technologies”

- Computer network: “a digital telecommunications network which allows nodes to share resources. In computer networks, computing **devices exchange data** with each other **using connections** between nodes (data links.) These data links are established over cable media such as wires or optic cables, or wireless media such as WiFi”



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A set of properties or values

Critical Property	Benefits
1 An Accessible Infrastructure with a Common Protocol that is open and has low barriers to entry	Unrestricted access and common protocols deliver global connectivity and encourage the network to grow. As more and more participants connect, the value of the Internet increases for everyone.
2 Open Architecture of Interoperable and Reusable Building Blocks based on open standards development processes voluntarily adopted by a user community	Open architecture creates common interoperable services, which deliver fast and permissionless innovation everywhere. The inclusive standardization process and demand-driven adoption ensures that useful changes are adopted, while unnecessary ones disappear.
3 Decentralized Management and a Single Distributed Routing System which is scalable and agile	Distributed routing delivers a resilient and adaptable network of autonomous networks, allowing for local optimizations while maintaining worldwide connectivity.
4 Common Global Identifiers which are unambiguous and universal	A common identifier set delivers consistent addressability and a coherent view of the entire network, without fragmentation or fractures.
5 A Technology Neutral, General-Purpose Network which is simple and adaptable	Generality delivers flexibility. The Internet continuously serves a diverse and constantly evolving community of users and applications. It does not require significant changes to support this dynamic environment.

ISOC, "The Internet Way of Networking – Defining the critical properties of the Internet", Sep 2020

Table 1: Abstract Architectural Criteria for Characterizing the Internet

Network Engineering	Economic
(1) layered architecture	(1) General Purpose Platform
(2) end-to-end packet connectivity	(2) Markets
(3) global address space	(3) Open Access
(4) interconnecting multiple ASes	(4) Permission-less Innovation
(5) global reach	(5) Decentralized, distributed ownership & control
(6) inter-AS routing protocol	
(7) shared set of standardized protocols	

W. Lehr, D. Clark, S. Bauer, A. Berger, P. Richter, "Whither the public Internet?", Journal of Information Policy 9, Aug 2019

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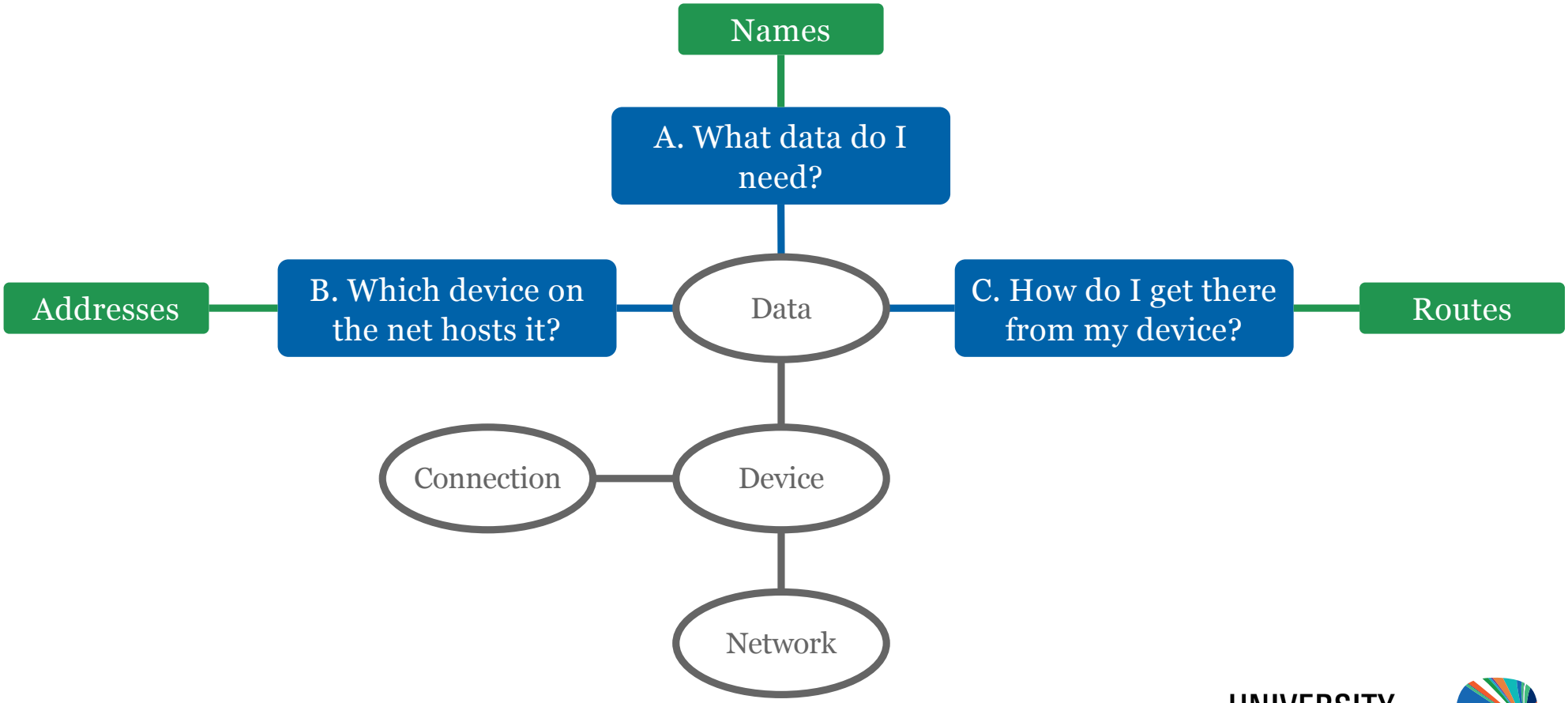
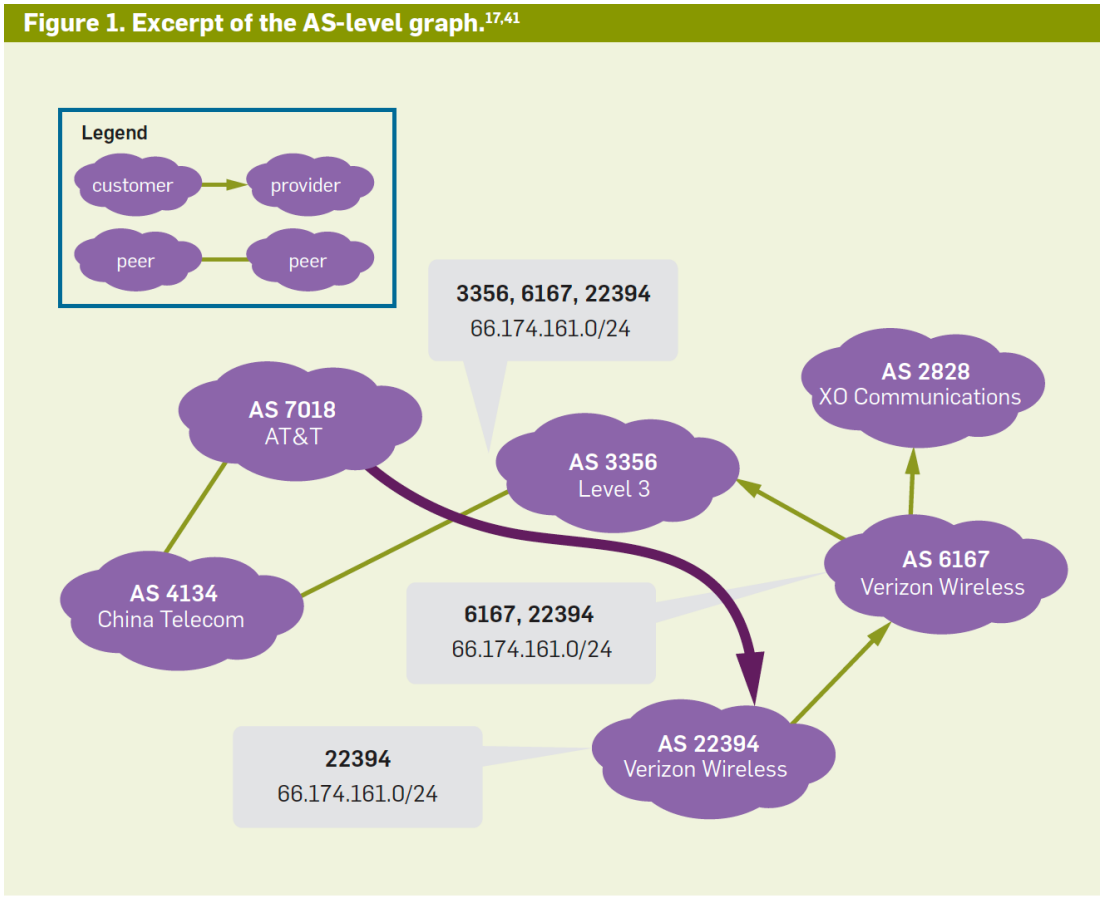
Key concepts of inter-networking (1978)



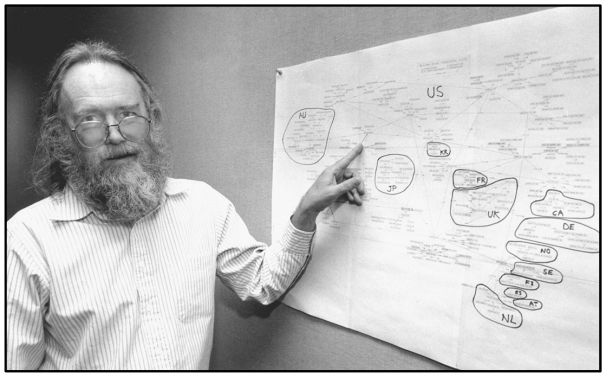
J. Shosh, “Inter-Network Naming, Addressing, and Routing”, Internet Experiment Note #19, January 1978

Largest collaboration ever

Figure 1. Excerpt of the AS-level graph.[17,41]



S. Goldberg, "Why is it taking so long to secure internet routing?", Communications of the ACM, Vol. 57, Issue 10, Oct 2014, pp. 56–63, https://doi.org/10.1145/2659899



"The Internet works because a lot of people **cooperate** to do things together"
– Jon Postel (1943-1998)

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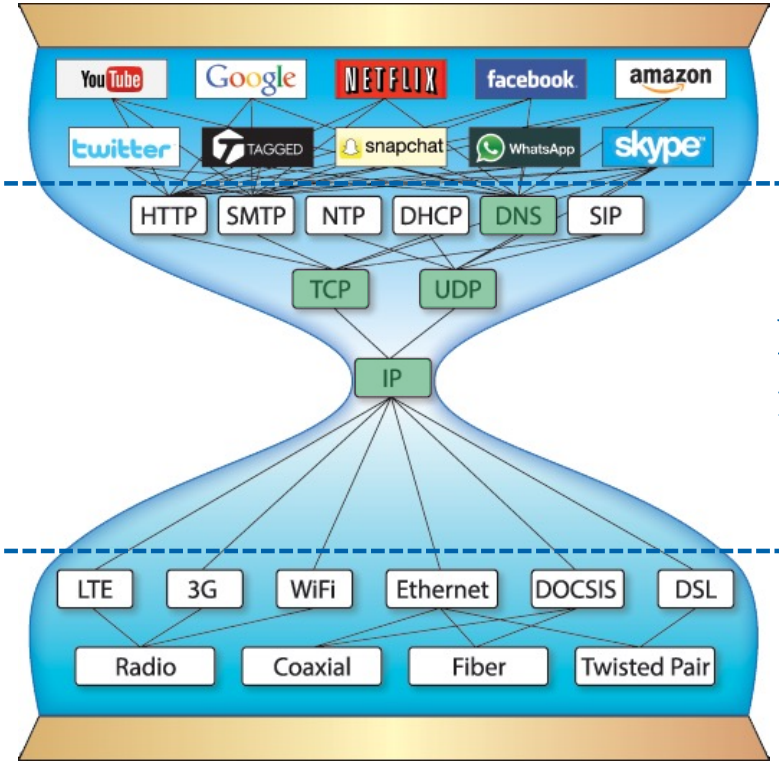
Under the hood: protocols and services

Most people

You and us



Services

Names, addresses, routes, transports

Transmission

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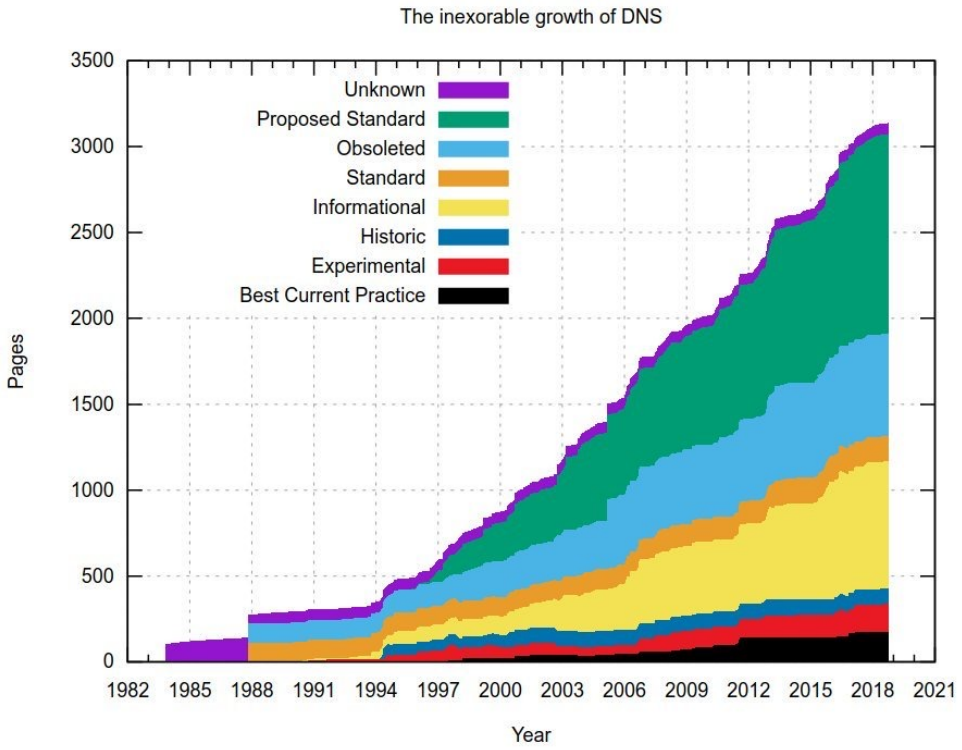
The complexity is huge



https://www.ietf.org/blog/herding-dns-camel/

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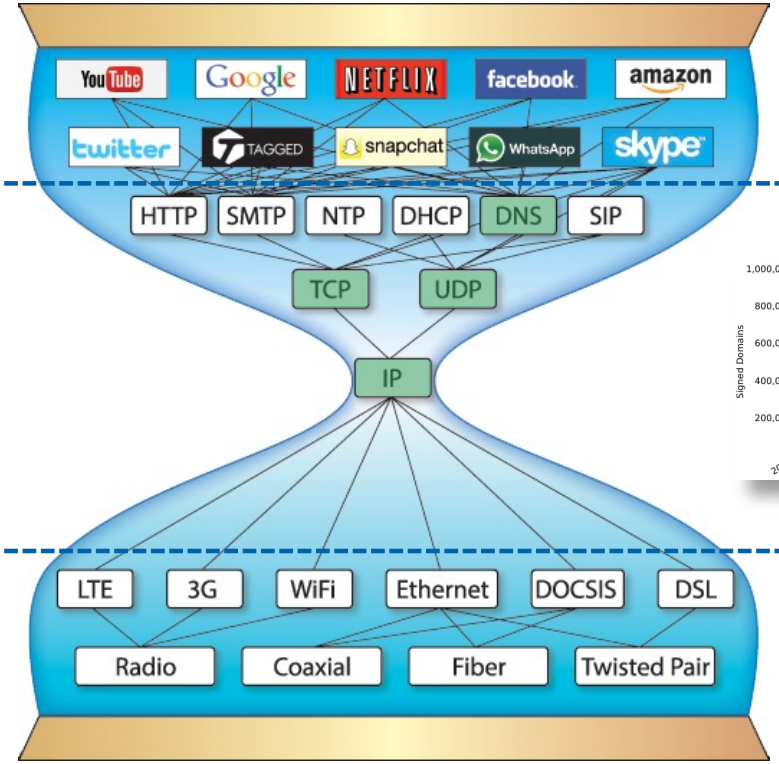
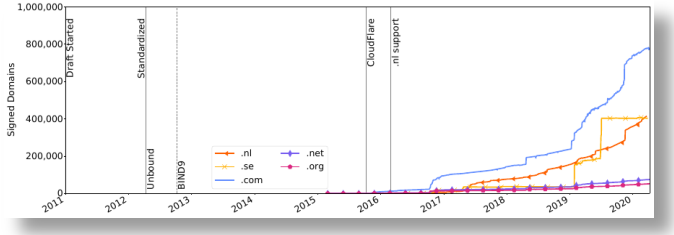
Rate of change

Fast

Slow!

Fast





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When did the Internet start?

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First packet ever: Oct 29, 1969

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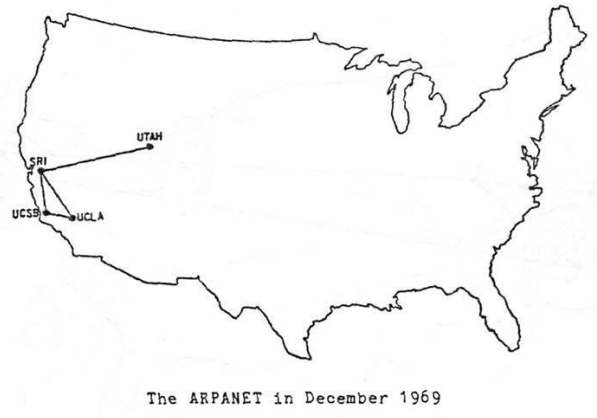
The origins of TCP/IP's design

Birthplace of the Internet
UCLA, Sep 2017



The ARPANET in December 1969

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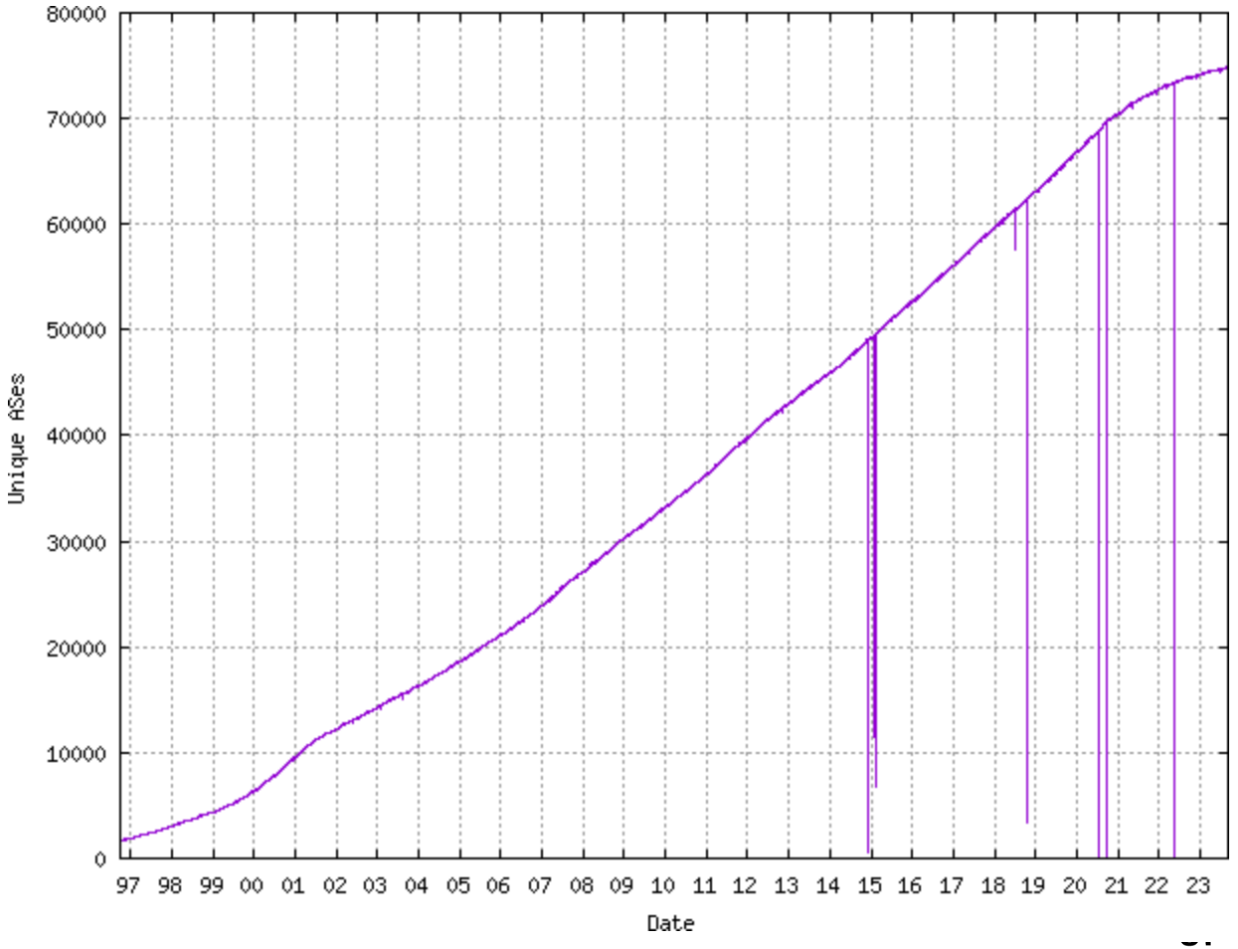
Fast forward to 2023

https://www.cidr-report.org/as2.0/



Where can the Internet be improved?

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TCP/IP lessons learned

- Thin waist enabled worldwide deployment
  - Simple network layer (IP+BGP), weak demands on underlying networks
  - Stateless, unreliable, unordered, best-effort delivery

- Additions investigated include:
  - Multipoint communications, in addition to point-to-point model
  - Security, which is largely an add-on instead of an integral part of the core protocols
  - Mobility management (movement between networks)
  - Restrict the impact of local incidents so they don't have global effects (e.g., a CA compromise)
  - Path verification capabilities

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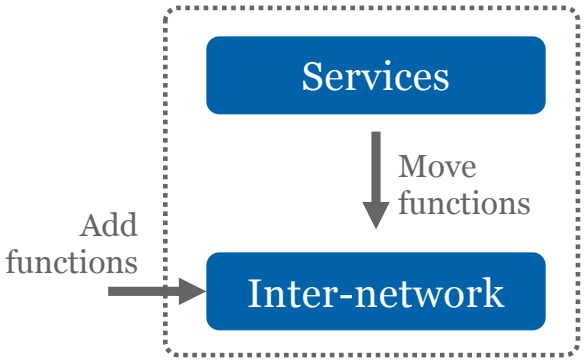
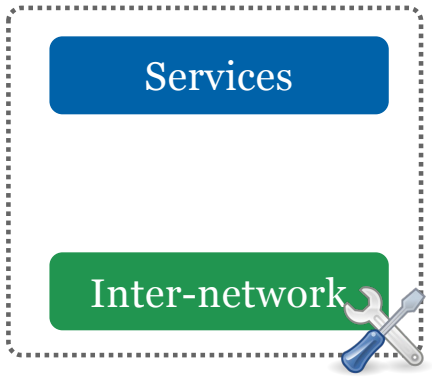
Proposed changes in the literature

Type 1: functional
Put functions not in TCP/IP in the (TCP/IP) network



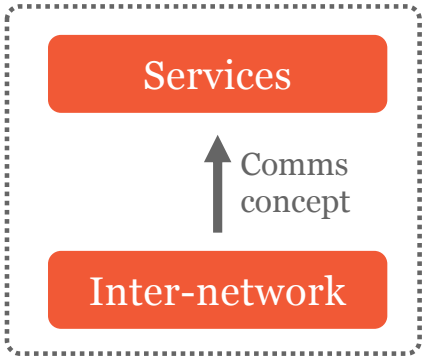
SCION
Responsible Internet
RINA
MobilityFirst
XIA

Type 2: design patterns
New generic structures for protocol stacks and/or (protocol) interfaces



TROSTKI ("layer 3.5")
RINA (layers)
XIA (addresses)
FII (interfaces)

Type 3: comms concepts
Network provides other comms abstraction than TCP/IP's host-based model



Data-centric
Service-centric
XIA, FII (future concepts)
ManyNets
Trust zones

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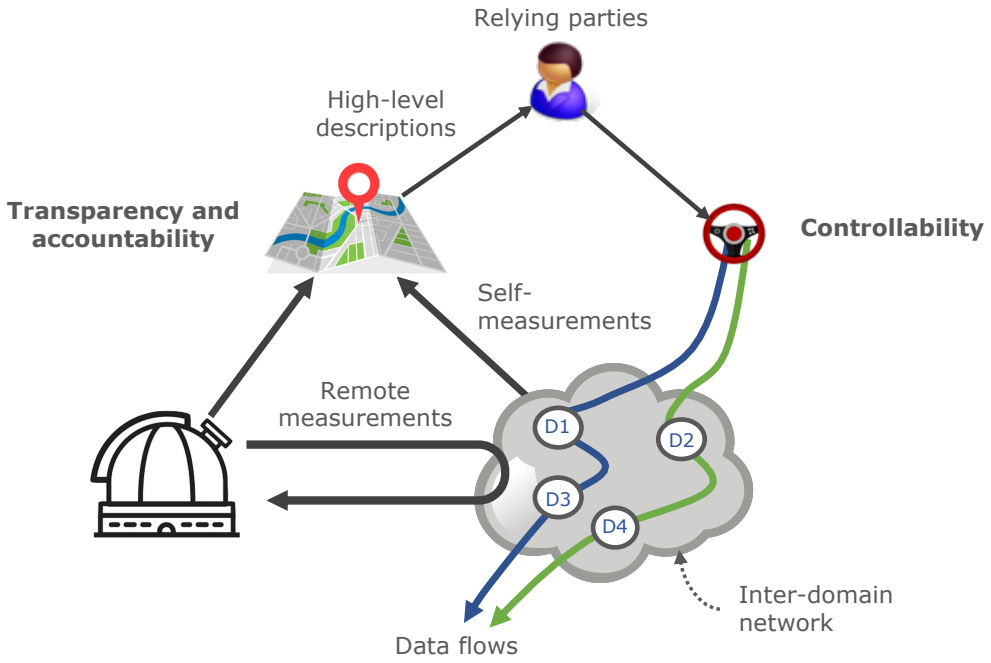
Example: the Responsible Internet

- Addresses lack of insight in and control over Internet's end-to-end structure and operation
- Tree new **design goals**: controllability, accountability, and transparency (CAT)
- Hypothesis: enables relying parties to communicate with more confidence and trust
  - Critical service providers
  - Policy makers
  - Network operators
  - Individuals



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Summary

- Relatively simple design of the Internet's core protocols solved problem of ubiquitous connectivity, Internet now critical for almost every aspect of our everyday life and for our society

- Challenge: how to align the Internet's services with society's increasing demands?
  - Higher levels of trust and autonomy to support new safety-critical applications
  - New network functions (e.g., security, privacy, real-time guarantees)
  - Draw inspiration from (open programmable) internet designs

- We expect that some of these new concepts will have an impact on deployed network infrastructure in the next few years and ANET will help you navigate that space

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Course overview

Details at https://courses.sidnlabs.nl/anet/

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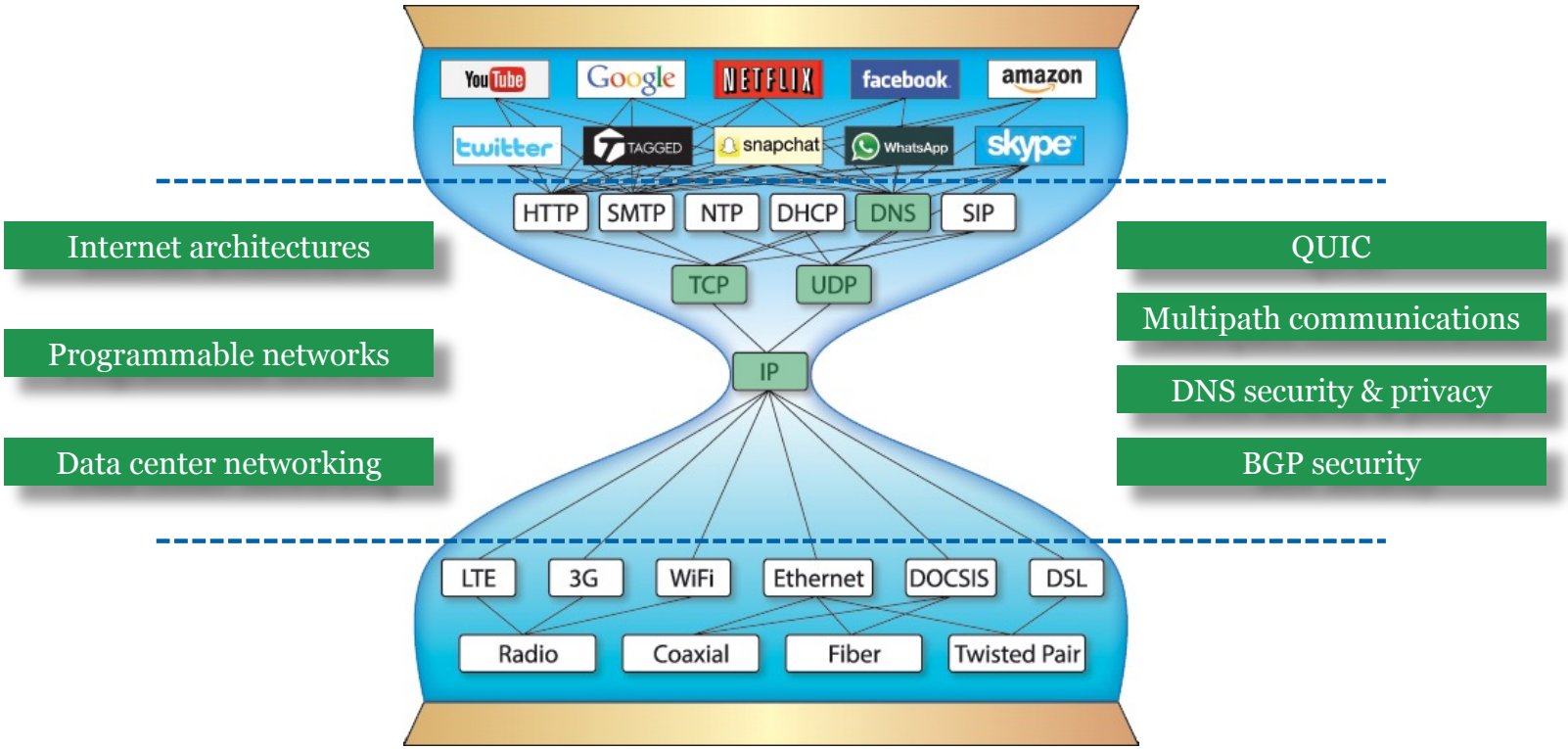
ANET topics



ANET is an **overview** course based on **research** papers. It complements Internet Security, which goes more into depth on the security of **specific Internet protocols**.

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Learning goals

- After successful completion of the course Advanced Networking (ANET) you will be able to:
  - Analyze, compare, and discuss various **advanced Internet concepts**, such as secure inter-domain routing and multi-path data delivery
  - Understand and discuss important **challenges and proposed experimental solutions**, including non-IP-based internetworking systems
  - Apply a domain-specific language such as **P4** to implement basic data plane functionality of an open programmable router, which is important for future Internet infrastructures

- Enhance your research skills because you'll need to independently review and analyze research papers and RFCs

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Prerequisites

- Introductory course on computer networks

- Such as the bachelor module Network Systems at the University of Twente

Make sure to **browse** a few of the ANET papers this week to double-check that ANET matches your interests, study plan, prerequisites, etc.

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Staying up to date

- ANET public homepage
  - https://courses.sidnlabs.nl/anet/
  - Authoritative source: papers, assessment, deliverables, etc.
  - Public site so other teachers/universities can potentially learn from our format

- ANET Canvas site
  - Announcements and communications
  - Uploading and archiving deliverables

- rooster.utwente.nl, in synch with public site

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ANET is a collaboration with SIDN Labs

- Motivation for SIDN Labs
  - Proud to help educating the next generation of Internet (security) engineers and researchers
  - Aligns with our research on secure future Internet infrastructures (www.2stic.nl)
  - Perhaps interest some of you to check out our work for an M.Sc. project ☺

- Extends ongoing academic-industry research collaboration
  - SIDN Labs: improve security and resilience of SIDN's services and wider Internet using latest academic insights, methodologies, network, and creative thinking
  - UT: further improved research and education using SIDN's operational experience, unique datasets, and industry network

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Lectures

https://courses.sidnlabs.nl/anet/

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Regular lectures

- Eight **interactive technical lectures**
  - Protocols and Internet architectures/deployments
  - Motivation: enhance your “networking horizon”

- Each lecture revolves around a **specific theme**
  - Topics cover core functions of inter-domain networking (e.g., naming, routing, security)
  - Motivation #1: give you a broad overview of advanced networking functions
  - Motivation #2: our research interests (we love to talk about the work we do :-)

- Attendance is **mandatory** because of group tests and discussions (see next slides)

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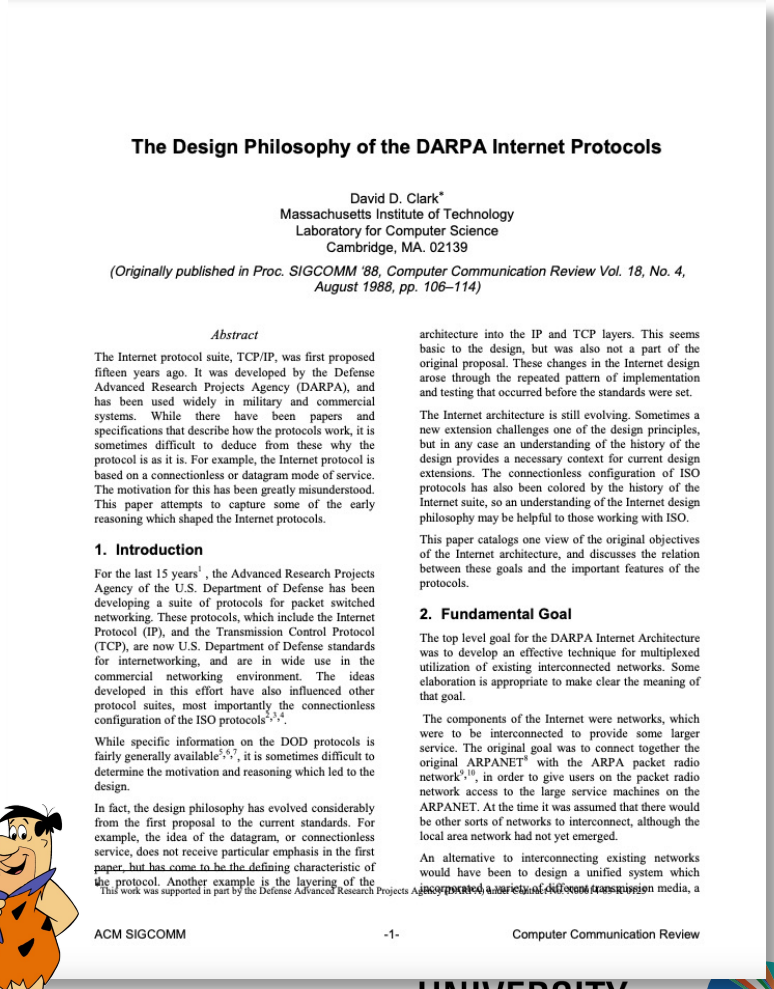
Themes

- "Going up the stack": programmable networks (hardware), BGP security, DNS security and privacy, multi-path communication, QUIC, data center networking, Internet architectures
- Papers cover a quarter of a century of networking research, with the oldest one from the Internet's proverbial "stone age" (1995)
- Help you understand generic network architectures and principles, not so much latest and greatest topics
- Additional reading on the ANET site



The Design Philosophy of the DARPA Internet Protocols

David D. Clark*
Massachusetts Institute of Technology
Laboratory for Computer Science
Cambridge, MA. 02139

(Originally published in Proc. SIGCOMM '88, Computer Communication Review Vol. 18, No. 4, August 1988, pp. 106–114)

Abstract

The Internet protocol suite, TCP/IP, was first proposed fifteen years ago. It was developed by the Defense Advanced Research Projects Agency (DARPA), and has been used widely in military and commercial systems. While there have been papers and specifications that describe how the protocols work, it is sometimes difficult to deduce from these why the protocol is as it is. For example, the Internet protocol is based on a connectionless or datagram mode of service. The motivation for this has been greatly misunderstood. This paper attempts to capture some of the early reasoning which shaped the Internet protocols.

1. Introduction

For the last 15 years[1], the Advanced Research Projects Agency of the U.S. Department of Defense has been developing a suite of protocols for packet switched networking. These protocols, which include the Internet Protocol (IP), and the Transmission Control Protocol (TCP), are now U.S. Department of Defense standards for internetworking, and are in wide use in the commercial networking environment. The ideas developed in this effort have also influenced other protocol suites, most importantly the connectionless configuration of the ISO protocols[2,3,4].

While specific information on the DOD protocols is fairly generally available[5,6,7], it is sometimes difficult to determine the motivation and reasoning which led to the design.

In fact, the design philosophy has evolved considerably from the first proposal to the current standards. For example, the idea of the datagram, or connectionless service, does not receive particular emphasis in the first paper, but has come to be the defining characteristic of the protocol. Another example is the layering of the architecture into the IP and TCP layers. This seems basic to the design, but was also not a part of the original proposal. These changes in the Internet design arose through the repeated pattern of implementation and testing that occurred before the standards were set.

The Internet architecture is still evolving. Sometimes a new extension challenges one of the design principles, but in any case an understanding of the history of the design provides a necessary context for current design extensions. The connectionless configuration of ISO protocols has also been colored by the history of the Internet suite, so an understanding of the Internet design philosophy may be helpful to those working with ISO.

This paper catalogs one view of the original objectives of the Internet architecture, and discusses the relation between these goals and the important features of the protocols.

2. Fundamental Goal

The top level goal for the DARPA Internet Architecture was to develop an effective technique for multiplexed utilization of existing interconnected networks. Some elaboration is appropriate to make clear the meaning of that goal.

The components of the Internet were networks, which were to be interconnected to provide some larger service. The original goal was to connect together the original ARPANET[8] with the ARPA packet radio network[9,10], in order to give users on the packet radio network access to the large service machines on the ARPANET. At the time it was assumed that there would be other sorts of networks to interconnect, although the local area network had not yet emerged.

An alternative to interconnecting existing networks would have been to design a unified system which incorporated a variety of different transmission media, a

This work was supported in part by the Defense Advanced Research Projects Agency (DoD), monitored by the Space and Naval Warfare Systems Command under contract N00039-84-C-0089.

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One theme per lecture

- One **introductory paper**
  - Tested through a closed book multiple-choice test in class
  - First do the test individually, then the same test in a group with 2-3 of your fellow students
  - Group test enables you to learn from your peers by discussing the test's questions

- Two **advanced papers** that explore the topic in more depth
  - Tested through a blog and a presentation
  - One or two presentations per lecture, schedule on the ANET site

- We'll publish the **best blog** on the ANET website (with the author's consent)

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Timetable (yes, micromanagement)

Time	What
10:45	Arrival, put your cell phone in your bag, pick up hardcopy of tests at teacher's desk, sit down
10:45-10:55	Individual test of introductory paper (closed book) Teacher will pick up the tests when everyone is done
10:55-11:00	Organize into groups (teacher divides you across groups)
11:00-11:10	Group test of introductory paper (closed book) Teacher will pick up the tests when everyone is done
11:10-11:30	Plenary discussion of the paper and the test
11:30-11:45	Break
11:45-12:00	Presentation #1 (10 minutes presentation, 5 minutes Q&A)
12:00-12:15	Presentation #2 (10 minutes presentation, 5 minutes Q&A)
12:15-12:30	Discussion of the two papers
12:30	Adjourn

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Guest lectures

- Goal: give you a flavor of operational network infrastructure and current research
- Fri Sep 29: Prof. Cristel Pelsser of Uni Louvain (BE) on routing research
- Fri Oct 13: Roeland Nuijts of Ciena Networks on submarine networking
- Open to everyone

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P4 lab exercises

- Intro today, extended intro next week (if necessary), two on-campus lab sessions

- Also work on the P4 lab assignment at home and not only at the lab sessions
  - Fixing bugs in P4 code might take time
  - Teaching Assistant needs to help multiple students

- Lab sessions run by Nathan (student assistant)

- More details in his talk :-)

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Your deliverables

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Overview

1. A total of **8 multiple-choice tests** on introductory papers
2. A **blog** in which you review one of the advanced papers
3. A **presentation** of 15 minutes about that paper at one of the lectures
4. Lab **exercises** about programing for a P4-enabled router

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Deliverable #1: multiple choice tests

- One topic per lecture (e.g., BGP security)

- One individual test per lecture: assess your understanding of the introductory paper
  - Grade = maximum of ((S-G)/(Q-G))*9+1 and 1

- One group test per lecture
  - Do the individual test once more, but in groups (group-based learning)
  - One open question on the main takeway of the paper (at most 25 words, must be a sentence)
  - Grade = maximum of ((S-G)/(Q-G))*8+O+1 and 1

- Not tested: 20 min open discussion at the end of each lecture

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Multiple-choice test example

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Test Advanced Networking (201700077)
Oct 23, 2019

Paper: M. Ammar, "Ex uno pluria: The Service-Infrastructure Cycle, Ossification, and the Fragmentation of the Internet", ACM SIGCOMM Computer Communication Review, Vol. 48, Issue 1, January 2018

Your name(s) and student number (s):

Individual test ☐ Group test ☐

Instructions:
- Please answer the questions by putting A, B, C, or D in the box on the right.
- Each correct answer gives you 1 point, a wrong answer will give 0 points.
- Individual test: provide 1 answer. Multiple answers will get you 0 points.
- Group test: you may give multiple answers. If the correct answer is among them, each group member gets 1/(the number of marked answers).
- We calculate the grade of your test in a way that compensates for filling out the test randomly
- This test is "closed book", i.e., no papers or any other materials allowed.
- Use of laptops, mobile phones etc. is not allowed.

Question #1 | **Your answer**

What's the main cause of the ossification of the Internet infrastructure?
A. The many Internet players make it difficult to agree on required changes.
B. Operators are unable to make a business case for changes to their networks.
C. The scale of the Internet makes it difficult to deploy new features.
D. All of the above.

Question #2 | **Your answer**

In the past, the ingredients to successfully introduce new Internet functions have been:
A. The ability to change unicast or multicast routing.
B. Iterations, experience from deployment, and new service requirements.
C. A testbed to experiment with the new functions.
D. Future service requirement that are also helpful in the present.

Question #3 | **Your answer**

Back in the early days, what goal was best served by moving from a ManyNets situation to a OneNet (i.e., the Internet as a common global network)?
A. Making network connectivity ubiquitously available.
B. Supporting every future service.
C. Experiment with OneNet's multiple-administrative-domains approach.
D. Standardization of network protocols

Question #4 | **Your answer**

What's the root cause for the transition from a OneNet back to a world of ManyNets?
A. Difficulty for researcher to experiment with new technologies in a OneNet.
B. Commercially available programmable routers make ManyNets possible.
C. New application requirements that the OneNet can't fulfill.
D. Service and content providers want to operate their own networks.

Question #5 | **Your answer**

What does the author consider a major challenge for the emerging ManyNets world?
A. Evolving a ManyNets infrastructure so that it meets new demands.
B. Connecting the ManyNets to the OneNet.
C. Being able to easily deploy new services in a ManyNet.
D. The ossification of individual networks in a ManyNet.

Question #6 | **Your answer**

With the re-emergence of ManyNets, the author suggests the networking research community to focus on:
A. Convincing everyone to go back to a OneNet.
B. De-ossifying the Internet.
C. The many new opportunities of ManyNets.
D. Interconnecting ManyNets.

Question #7 | **Your answer**

In what sense is 5G an example of the emergence of ManyNets?
A. It is a separate network not connected to the Internet.
B. Google will create its own wide-area network because they can't use 5G.
C. 5G "slicing" splits the network into three different sets of capabilities.
D. 5G networks only serve large numbers of IoT devices

== END OF TEST ==

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Deliverable #2: blog (1/2)

- 1.500 words tops on an advanced paper
- Goal: readers should be able assess if they'd like to read the full paper based on your blog
- Your target audience are readers with a background in computer networking
- The blog must be self-contained and capture the essence of the paper
- Start with a section in which you explain the paper's three main takeways (<= 150 words)
  - See "Key Insights" on page 1 of [SCION] for an example

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Deliverable #2: blog (2/2)

- At the end of your blog, briefly reflect on (<= 100 words, does not add to the word count):
  - The process you followed to study the paper, understand its contents, and write the blog
  - How you incorporated the feedback you received at your presentation

- Also include an appendix that says (does not add to the 1.500 words):
  - “I wrote this blog myself. I used [TOOL/SERVICE] exclusively to improve the language of the blog and not to generate content that I had not already written myself. I fully reviewed the [TOOL/SERVICE]-revised versions of the blog and take full responsibility for its content.”, OR
  - “I did not use any artificial intelligence tools to write my blog.”
  - In line with UT policy on use of AI: https://www.utwente.nl/en/learning-teaching/expertises/AI%20In%20Education/use-of-ai-in-education-at-the-university-of-twente.pdf

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Example topics

Design paper (e.g., [SCION])	Measurement paper (e.g, [DNS-SP])
• What is the problem that the authors aim to solve? • What requirements do the authors articulate for their work? • What does the high-level design and operation of their proposed system look like? • How does the design address the requirements? • What are the pros and cons of the authors' work and why? • What would you do differently? • Would you recommend the paper to interested readers?	• What is the problem that the authors aim to solve? • What methodology and experimental setup do the authors use? • What are their key findings and conclusions? • How do they propose others use their measurement study? • What are the pros and cons of the authors' work and why? • What would you do differently? • Would you recommend the paper to interested readers?

Write the blog in your own words

Style		Example
Citing	✓	In our lab experiment, we use Manufacturer Usage Descriptions (MUDs) [RFC8250] to describe the network behavior of IoT devices.
Quoting	✓	MUD was designed to "provide a means for end devices to signal to the network what sort of access and network functionality they require to properly function" [RFC8250]
Copying	✗	MUD was designed to provide a means for end devices to signal to the network what sort of access and network functionality they require to properly function [RFC8250]

- Also cite and quote sources where you are a co-author, if applicable

- As per the university's policy, no forms of plagiarism are tolerated (check through Canvas)

Who writes about which paper?

- Indicate your **ranked top 5** (1st, 2nd, 3rd, etc.) through Canvas by **Wed Sep 6, EOB**

First name	Blogs about
…	[…]
…	[…]
…	[…]
…	[…]
…	[…]
…	[…]
…	[…]
…	[…]
…	[…]
…	[…]

Grading of your blog

- We will evaluate your blog based on the following criteria:
  - Understanding: how well did you understand the paper, for instance in terms of the problem it aims to solve and the paper's key points?
  - Analysis: to what extent did you provide a critical analysis of the paper, for instance in terms of the pros/cons of the work, limitations of the proposed solution/approach, and potential improvements?
  - Clarity: structure, language, and readability of the blog

- The ANET teacher who gives a particular lecture will evaluate the blogs of that lecture
  - In addition, one of the other teachers will review your blog for a cross-check
  - They both use the evaluation criteria listed above to grade your blog

Deliverable #3: presentation

- Present 1 advanced paper to your peers in at most 15 minutes, including 5 minutes of Q&A
- Give your three main take aways of the paper on your first slide
- Teachers will score based on clarity, structure, and how well you responded to questions
- Your fellow students will do the same through a feedback form that we'll hand out
- Pointers on how to make a presentation are on the ANET website

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Deliverable #4: P4 lab assignment (1/2)

- Goal: learn how to program the packet handling functions of a simulated router using the domain-specific language P4

- Carry out the P4 assignment **individually** during the two lab sessions or at home

- Teaching Assistant (Nathan) signs off **at one of the two lab sessions**

- Key **requirements** you'll need to fulfil to get your P4 assignments signed off are:
  - Your P4 code needs to run and shows the expected behavior
  - You're able to explain the Teaching Assistant what's going on and why
  - You added comments to your P4 code explaining what you did and why

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Deliverable #4: P4 lab assignment (2/2)

- Work on the P4 lab assignment **at home** and not only at the lab sessions!
  - You might need to fix bugs that will take time to find
  - The Teaching Assistant needs to help multiple students at the lab sessions, so might not always be immediately available for you

- We'll have a paper on P4 in the second lecture

- Nathan will provide a lab intro after my talk

- Potentially an extended introduction on Wed Sep 13

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Assessment

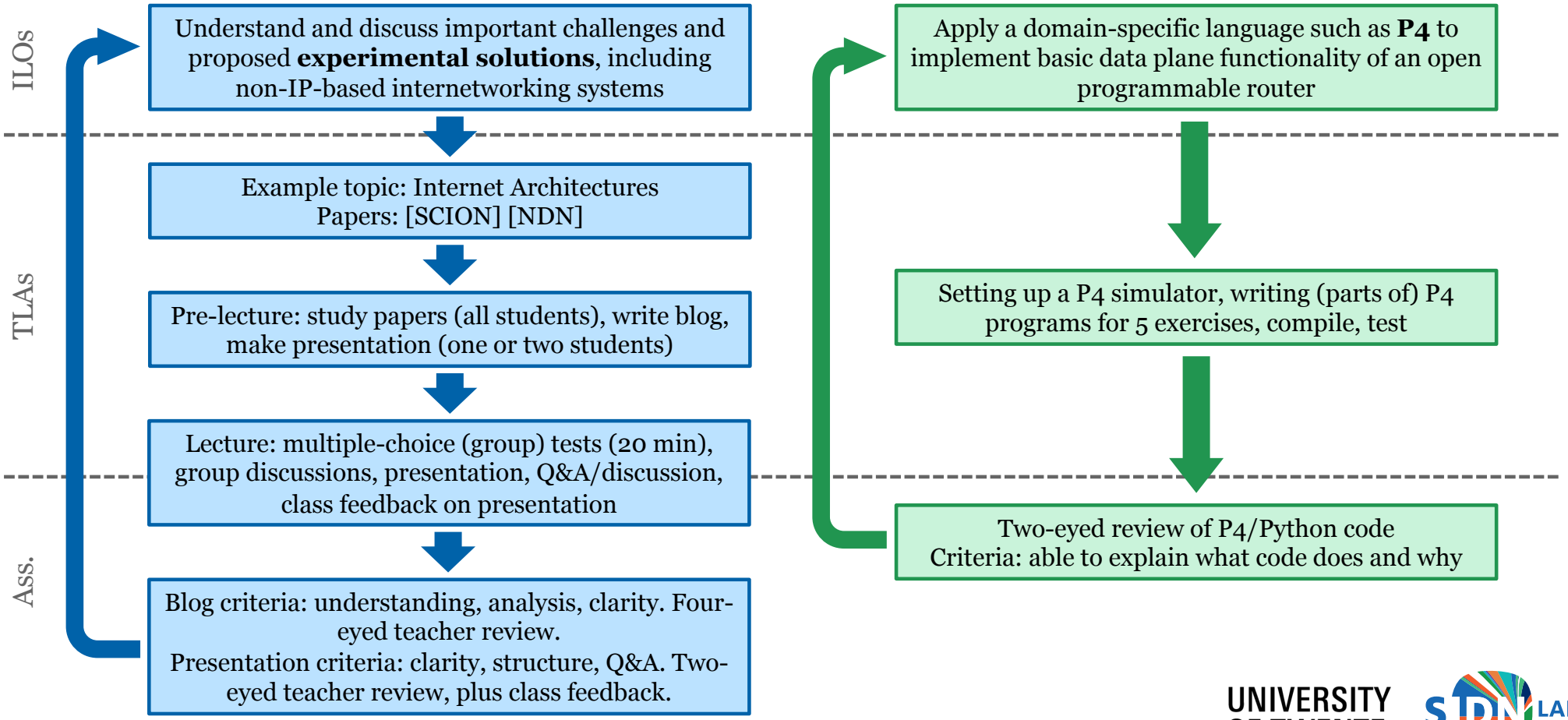
- Goal: evaluate to what extend you attained ANET's learning goals

- Pass if (((average score of your 8 individual tests)*25% + (average score of your 8 group tests)*25% + (score of your blog)*40% + (score of your presentation)*10%) * (score of your lab assignment)) >= 5.5

- The scores of the tests, blog, and presentation are between 1 (worst) and 10 (best)

- The score of the lab assignment is either 1 (pass) or 0 (fail)

Connecting it all: learning goals, activities, assessment



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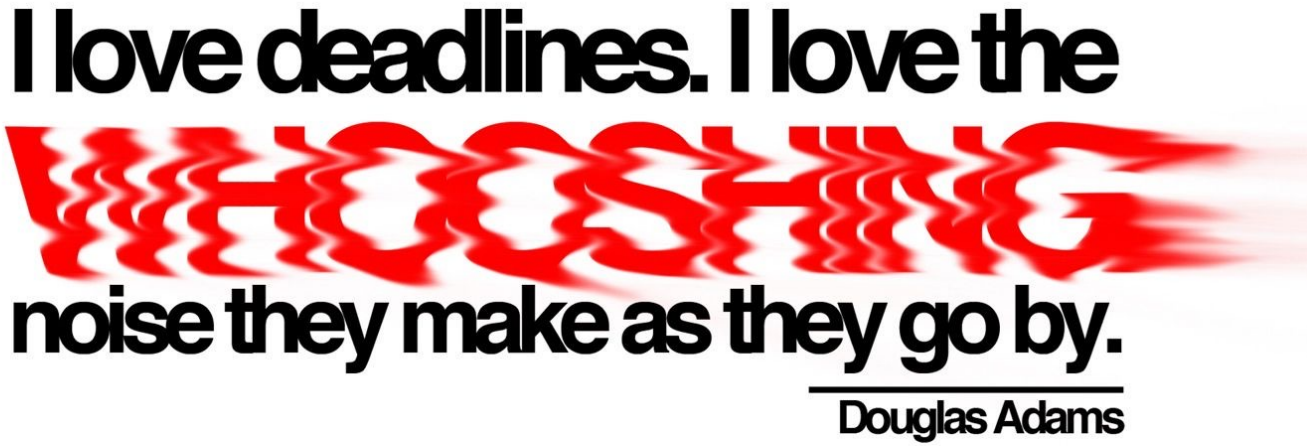
Important dates

- Ranked top five of papers you'd like to blog about (1st, 2nd, etc.): **Wed Sep 6, 2023**
- Individual and group test: **at each lecture**
- Blog: **one week after** the lecture in which you presented the paper
- Lab assignment: by the **end of the last lab session** (see ANET schedule)
- Notification of grades: **two weeks** after the last lecture, so around Nov 22, through Canvas

Plan ahead!

- You need to deliver every week

- Writing a good blog and making a presentation takes time!



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Change log

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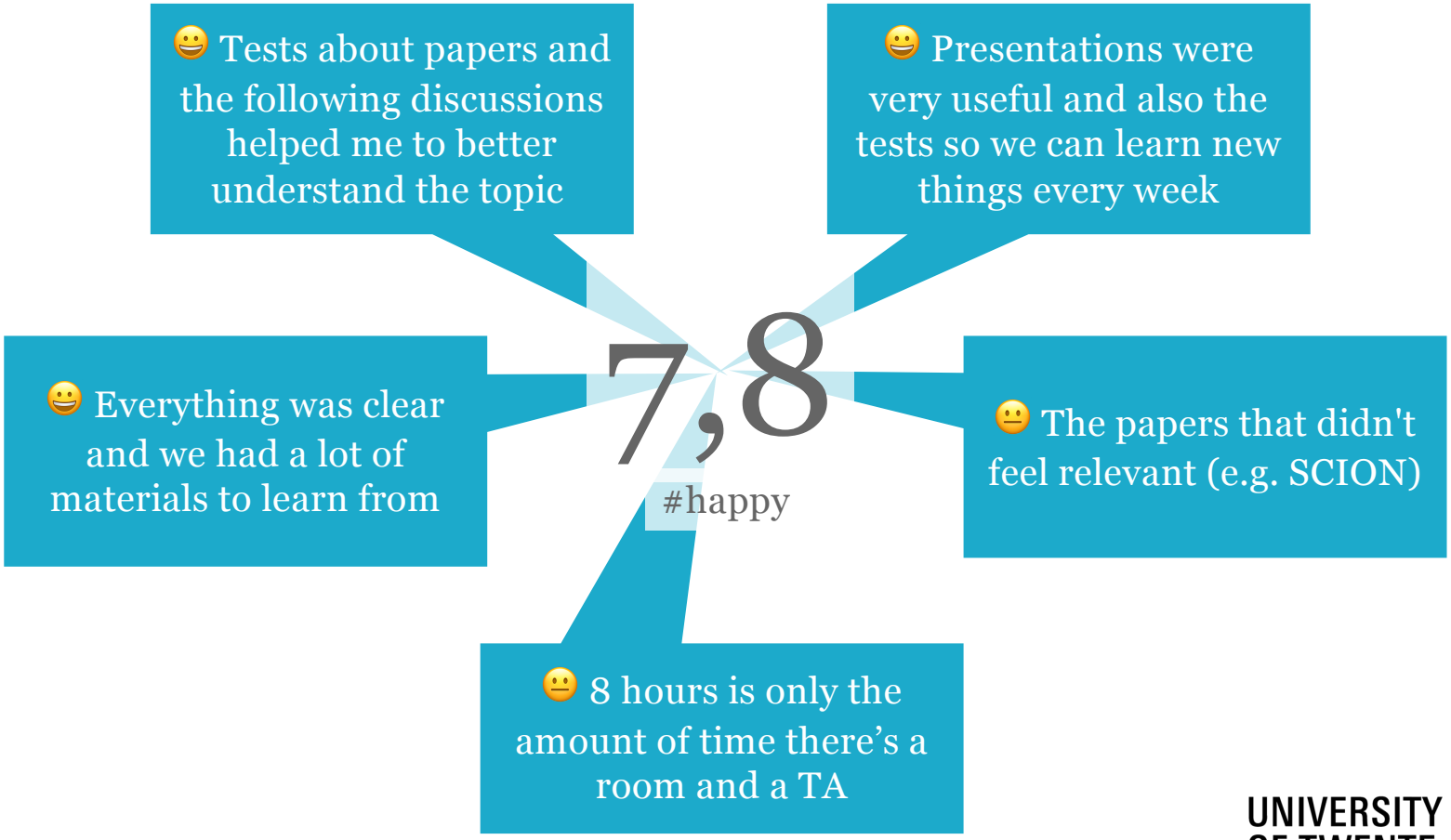
Class of 2022/2023 feedback (summary)



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Changes based on feedback class of 2022/2023

- Added focus on key points of papers (group test, presentation, blog)
- Provided an example of a test (see earlier slides)
- Emphasized that we recommend you also work on the P4 lab at home
- Brushed up the P4 exercises
- Replaced paper [ICING] with [FABRID]
- We were stubborn and kept the SCION paper ;-)

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P4 lab assignment

Nathan Djojomoenawie

University of Twente | September 6, 2023

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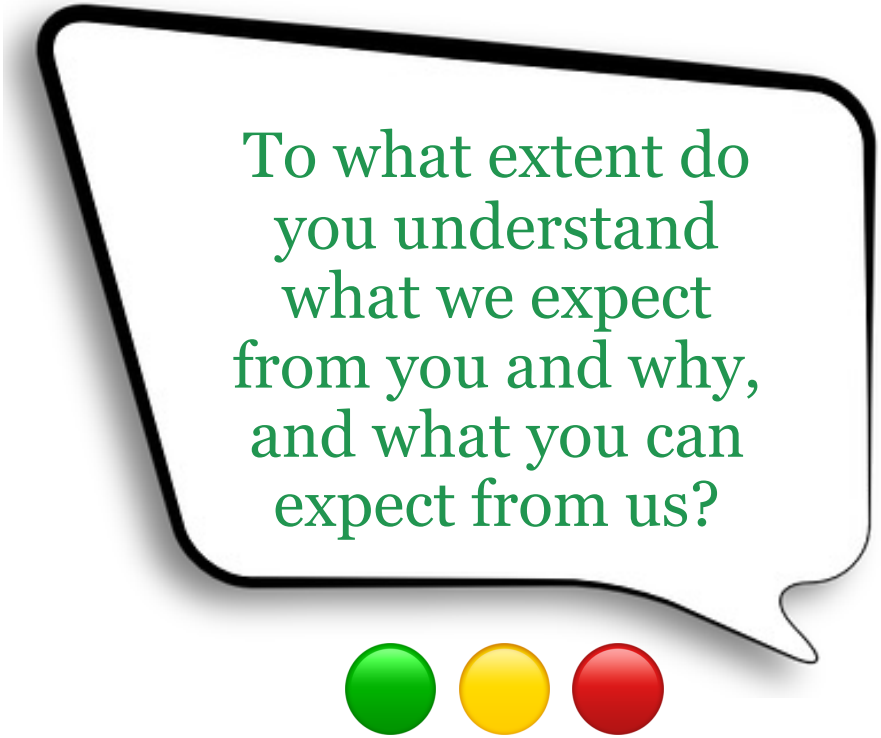
To what extent do you understand what we expect from you and why, and what you can expect from us?



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Fact sheet

Advanced Networking (ANET)	
EC	5 (140 hours)
Prerequisites	Introductory course in computer networking, such as the bachelor module Network Systems at the UT
Coordinator	Cristian Hesselman (SIDN Labs, University of Twente)
E-mail	c.e.w.hesselman@utwente.nl
Teaching team	Dr. Pieter-Tjerk de Boer Prof. Geert Heijenk Prof. Roland van Rijswijk-Deij Nathan Djojomoenawie (TA) Prof. Cristian Hesselman
Quartile	1A (Sep 6 thru Nov 10, 2023)
Academic year	2022/2023
Capacity	Max 16 students

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Volg ons

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Q&A

Next lecture: **Wed Sep 13, 08:45-10:30**
Topic: programmable networks

Cristian Hesselman
Director of SIDN Labs

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