Network Design and Optimization course

Lecture 1

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- Teacher:
  Alberto Ceselli alberto.ceselli@unimi.it
- Course weekly schedule:
  - Wednesday (14.00 – 16.00)
  - Friday (11.00 – 13.00)
- Tutoring: TBA (anytime after the lectures, but also in other time slots: contact me by email)
- Homepage:
  www.dti.unimi.it/ceselli/NDO

Reference books:

- M. Pioro and D. Medhi, *Routing, Flow and Capacity Deisign in Communication and Computer Networks*; Morgan Kaufmann Eds.
- R.K. Ahuja, T.L. Magnanti, J.B. Orlin, *Network Flows*; Prentice Hall Eds.
- More detailed links during the course ...
- Exam:
  - development of a *project* (Model + Algorithm + Experimental analysis + Technical report)
  - project discussion

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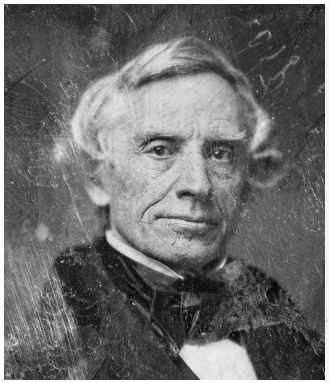
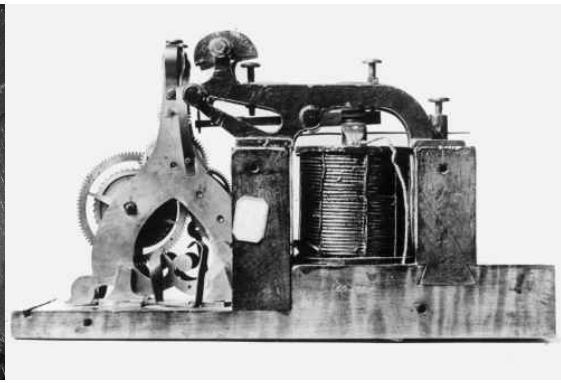
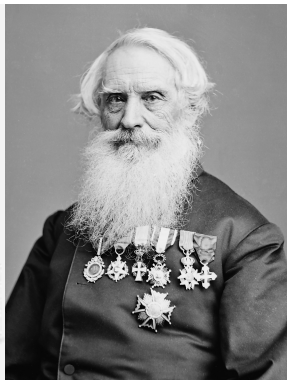
  - development of a *project* (Model + Algorithm + Experimental analysis + Technical report)
  - project discussion
- Any question on practical issues?

From Morse ...

Samuel Morse (1791 – 1872)

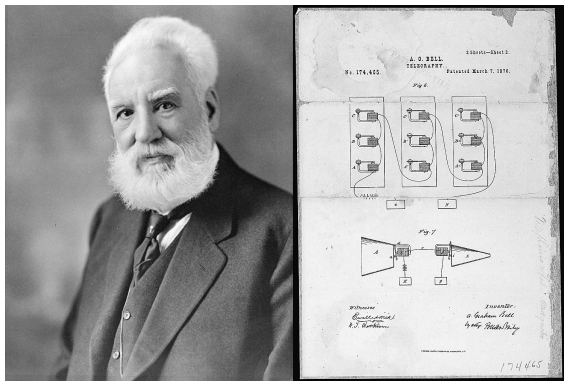
- professor of arts and design at New York University
- in 1835, proved that signals could be transmitted by wire ...

... to Bell ...

Alexander Graham Bell (1847 – 1922), and Thomas Watson

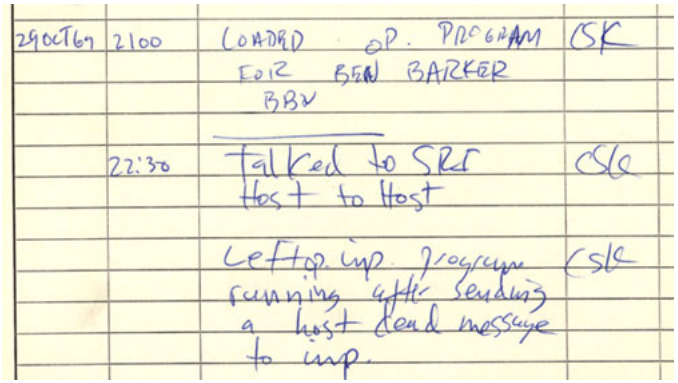
- initially working on *multi-tone* telegraphy (many signals on the same line at the same time)
- multi-tone then became the *telephone*!
- patented during 1876 ...

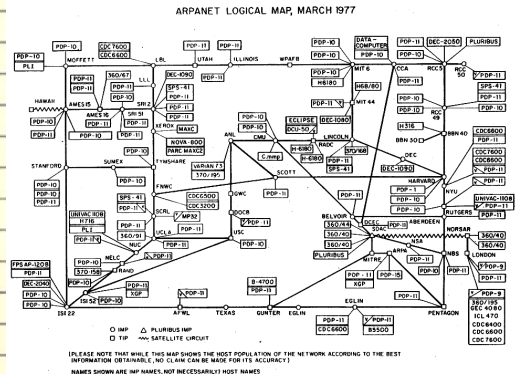


... to ARPANET ...

The Advanced Research Projects Agency Network (ARPANet),

- J. C. R. Licklider, articulated the ideas in his January 1960 paper, Man-Computer Symbiosis,
- first operational packet switching network between computers ...
- actually deployed in 1969 ...
- the first message "LO(G)" yielded a system crash!





... to Ethernet ...

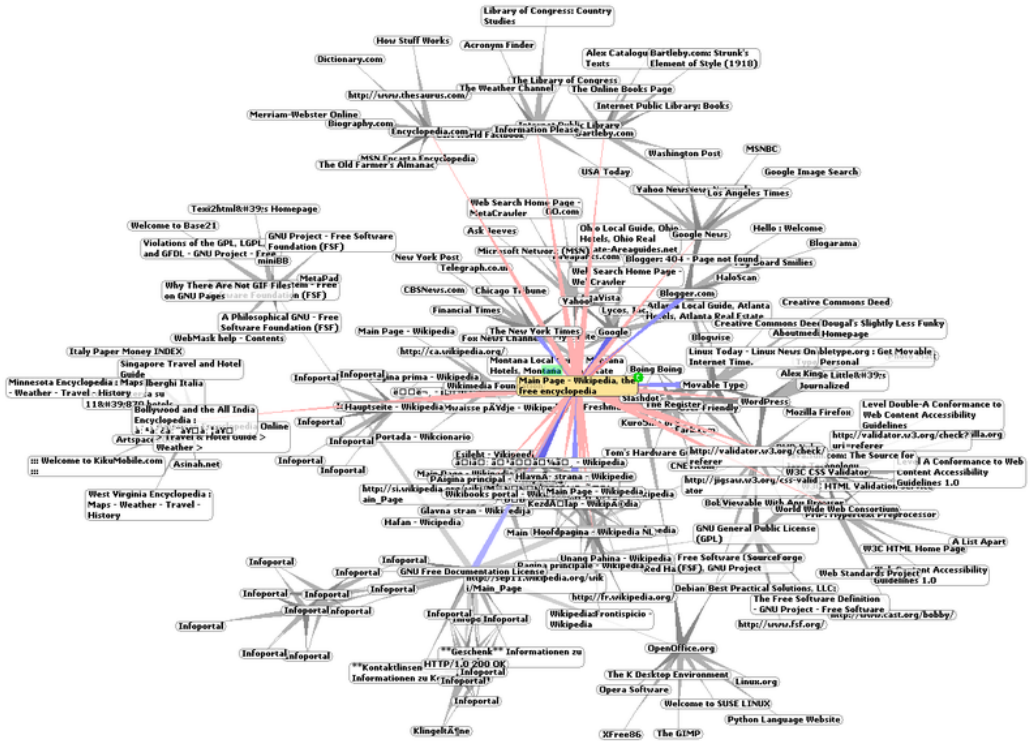
Ethernet was developed at Xerox PARC between 1973 and 1974.

- transmission rate of 10 Mbit/s,
- network of 10000 computers in 1986.

... to the World Wide Web ...

WWW: a system of interlinked hypertext documents

- Tim Berners-Lee wrote a proposal in March 1989 ...
- Robert Cailliau proposed in 1990 to use hypertexts ...



... to Google and FB.

Google (Larry Page and Sergey Brin in 1998):

- over 1 million servers, at least 12 data centers located only in the U.S.A.;
- internet search: about 24 PB of user data daily;
- cloud computing: managing and balancing distributed resources.

Facebook (Mark Zuckerberg et al. in 2004):

- handling *social* networks of several hundred million users ...

What's the lesson to learn?

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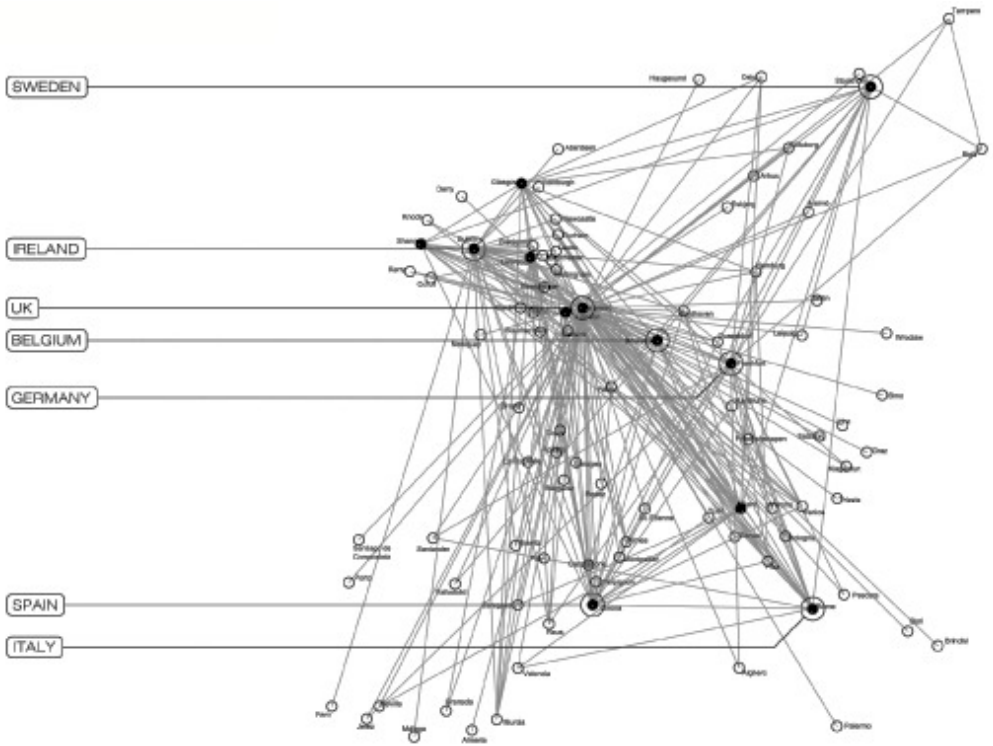
A few observations:

- networks are pervasive;
- network problems moved from technologies to applications, and now to *services*;
- by "network" we mean far more than computers connected by cables;
- networks are in general too complex to be managed by humans without decision support systems.

Routing for dummies

Let's consider a flight metaphore ...



How to fly from Milan (Italy) to Torp (Norway)?
Issues: travel times and costs, connection delays, flight capacities ...

An example of network design

Design in urban transit networks ...

What's the best connection for a new urban ring?
Issues: building costs, *improvement in routing* ...

Robustness and resilience

What happens if a link or a node of the networks fails?

Which are the critical connections?

Issues: budget, *worsening in routing* ...

Common ground

Airlines	Telecomm.	NDO course
airport	computer	node
flight	network connection	link
people moving	(data) packets transfer	traffic
ways of reaching the airports		access network
whole airport connections		core (or backbone) network
seats on an airplane	link bandwidth	capacity
travel time, lost luggage, delay, cost ...	communication time, packets lost, energy ...	quality of service
wait at an airport for next connection	buffer and transmit packets	store-and-forward paradigm (i.e. packet switching)

Appropriate questions

Given a telecommunication network (structure and routing) ...

- Can we find better routes?
- Where should we add more bandwidth?
- Where and when should we add more nodes / links in the network?
- What level of abstraction is appropriate for modeling a particular network, so that meaningful results can be obtained?

How to *design* cost-effective *networks*? (mainly core/backbone ...)

Course Objectives:

In this course we'll try to learn:

- how to formally represent a network,
- how to model its behaviour using mathematical programming tools,
- how to formalize optimization problems (e.g. design, routing, protection ...) on it,
- how to solve them by means of general purpose solvers and/or,
- how to devise suitable ad-hoc algorithms,
- how to provide quantitative performance analyses of networks.

In this course we **do not** cover:

- technological equipment issues.

Course "spirit":

How? With a "problem-solving driven" attitude ...

- description of a practical network problem,
- mathematical modeling,
- study and implementation of solution algorithms,
- computational tests.

What background is needed?

- Some coding skills (but no "bit-slicing" skills needed!),
- Algorithms and data structures,
- Operations research basics,
- (Design and analysis of algorithms).

What programming languages will be covered

Goal: learn how to solve network optimization problems

- code efficiency is not the main issue;
- flexibility and possibility of "understanding by testing" is more important;
- $\rightarrow$ AMPL (or its MathProg dialect).

Course Program

Part I: basic optimization problems on networks

- routing: shortest paths, max flow, min cost flow;
- design: minimum spanning trees and forests, min cut;

partially covered also by the "Operations Research: complements" course.

Course Program

Part II: advanced optimization problems on networks

- routing: multicommodity flows, generalized flows;
- design: hub location (medians, centers ...), Steiner trees, multi-layer networks;
- resource allocation: generalized and quadratic assignment.

Course Program

Part III: protection and reliability

- protection againts link failures;
- protection againts node failures.

Course Program

Methodologies:

- dynamic programming;
- linear programming and integer rounding;
- lagrangean relaxations and heuristics;
- local search;
- approximation methods.

Course Program

Questions????