Università degli Studi dell'Aquila

Academic Year 2016/2017

Course: Non-cooperative networks (3 CFU) (this course is integrated within the NEDAS curriculum with "Social networks" (3 CFU), by Dott. Gianpiero Monaco, to form the "Autonomous Networks" course)

Instructor: Prof. Guido Proietti

Schedule:	Wednesday:	8.45 – 10.30 – Room A1.5
	Thursday:	11.30 – 13.15 – Room C1.16
Questions?:	Tuesday	16.30 - 18.30 (or send an email to guido.proietti@univaq.it)

Slides plus other infos:

http://www.di.univaq.it/~proietti/didattica.html

What a (communication) network is about

In the old days: a number of workstations over a LAN

Today

Collaborative Computing Systems

- Military command and control
- Online strategy games
- Massive computation

Distributed Real-time Systems

- Process Control
- Navigation systems, Airline Traffic Monitoring (ATM)

Mobile Ad hoc Networks

Rescue Operations, emergency operations, robotics

Wireless Sensor Networks

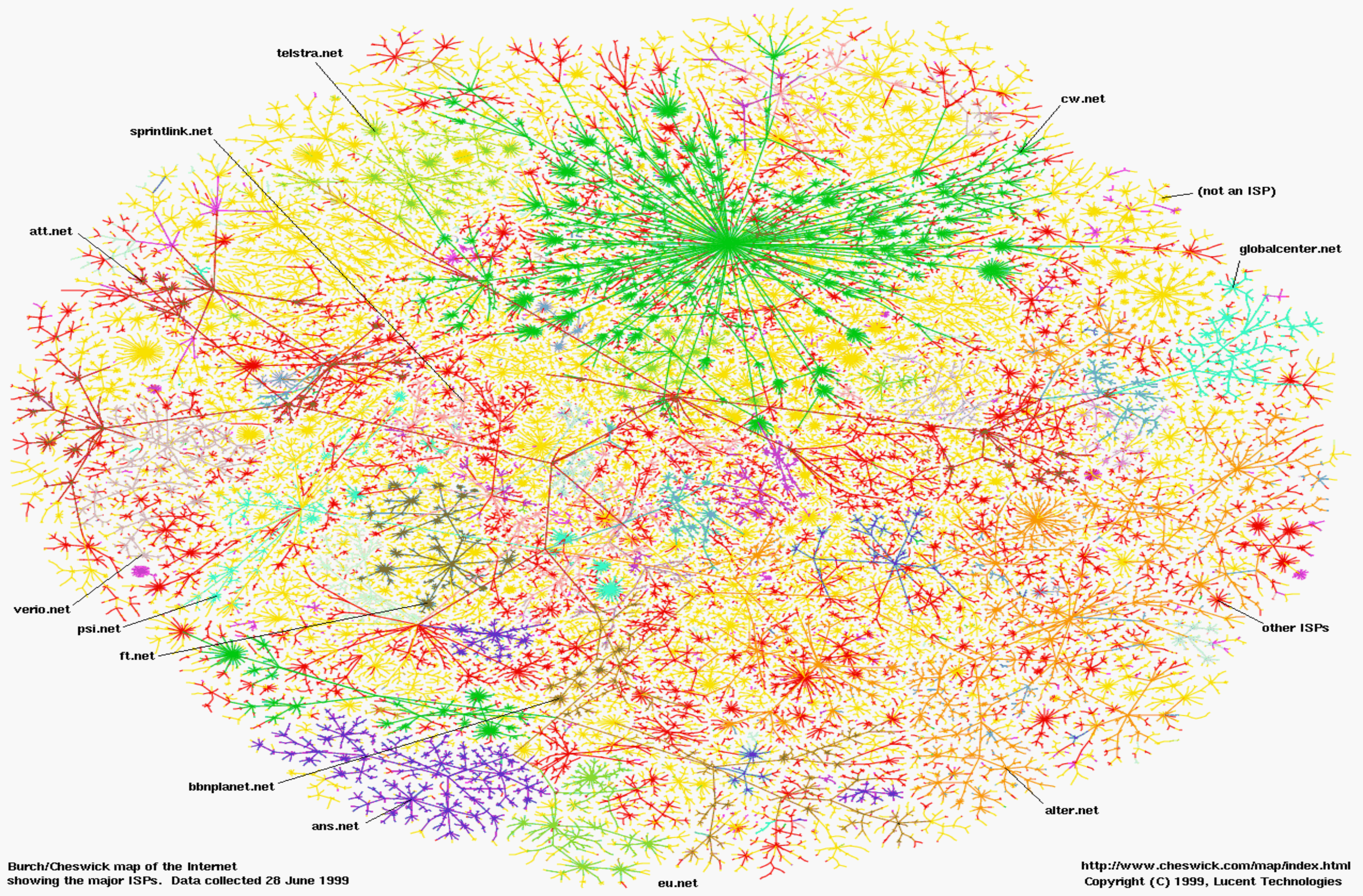
Habitat monitoring, intelligent farming

Social Networks

Grid and Cloud computing

…

And then, the mother of all the networks: the Internet



Burch/Cheswick map of the Internet
showing the major ISPs. Data collected 28 June 1999

http://www.cheswick.com/map/index.html
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Lack of cooperativeness in large networks

Large networks (e.g., Internet) are built and controlled by diverse and competitive entities:

- Entities own different components of the network and hold private information
- Entities are selfish and have personal preferences

⇒ The classic **network optimization** field of research (where selfishness is not considered) does not fit properly!

Three main ingredients in the course: Networks + Algorithms + Game Theory

Non-cooperative Network (NCN): Broadly speaking, we refer to it as a set of **autonomous (i.e., non-cooperative) computational devices** (say, **processors** or **agents**) performing multiple operations/tasks simultaneously, and which influence reciprocally either by **taking actions** or by **exchanging messages** (using an underlying wired/wireless **communication infrastructure**)

We will be concerned with the **computational** and **game-theoretic aspects** of a NCN. We will analyze a NCN by assuming that each agent chooses **strategically** and **non-cooperatively** how to behave, by aiming to maximize his personal benefit. Our topic is a subfield of the larger emerging Algorithmic Game-Theory (AGT) field.

Course structure

FIRST PART: Strategic equilibria theory in NCN

1. Nash equilibria
2. Selfish routing
3. Network Design games
4. Network Creation games

SECOND PART: Implementation theory in NCN

1. Algorithmic mechanism design (AMD)
2. AMD for some basic graph optimization problems

Mid-term **Written** Examination (at the end of the first part of the program): 10 multiple-choice tests, plus an open-answer question

Final **Oral** Examination: this will be concerned with either the whole program or just the second part of it, depending on the outcome of the mid-term exam. There will be fixed a total of 6 dates, namely:

- 3 in January-February
- 2 in June-July
- 1 in September

For those enrolled in the NEDAS curriculum, there will be a single final grade as a result of the grades obtained in this course and in the 'Social Networks" course; the corresponding exams can be done separately, but they must be sustained within the same calendar year

Suggested readings

- *Algorithmic Game Theory*, Edited by Noam Nisan, Tim Roughgarden, Éva Tardos, and Vijay V. Vazirani, Cambridge University Press.
- Blog by Noam Nisan http://agtb.wordpress.com/

Algorithmic Issues in Strategic (Non-cooperative) Distributed Systems (Networks)

Two Research Traditions

- Theory of Algorithms: computational issues
  - What can be feasibly computed?
  - How long does it take to compute a solution?
  - Which is the quality of a computed solution?
  - Centralized or distributed computational models
- Game Theory: interaction between self-interested individuals
  - What is the outcome of the interaction?
  - Which social goals are compatible with selfishness?

Different Assumptions

- Theory of Algorithms (in distributed systems):
  - Processors are *obedient*, *faulty (i.e., crash)*, *adversarial (i.e., Byzantine)*, or they compete without being strategic *(e.g., concurrent systems)*
  - Large systems, limited computational resources

- Game Theory:
  - Players are *strategic* (selfish)
  - Small systems, unlimited computational resources

The Internet World

- Users often selfish
  - Have their own individual goals
  - Own network components
- Internet scale
  - Massive systems
  - Limited communication/computational resources

⇨ *Both strategic and computational issues!*

Fundamental question

- How the computational aspects of a strategic distributed system should be addressed?

Algorithmic Game Theory = ***Theory of Algorithms*** + ***Game Theory***

Basics of Game Theory

- A game consists of:
  - A set of players (or agents)
  - A specification of the information available to each player
  - A set of rules of encounter: Who should act when, and what are the possible actions (strategies)
  - A specification of payoffs for each possible outcome (combination of strategies) of the game
- **Game Theory** attempts to predict the final outcomes (or solutions) of the game by taking into account the individual behavior of the players

Solution concept

How do we establish that an outcome is a solution? Among the possible outcomes of a game, those enjoying the following property play a fundamental role:

- Equilibrium solution: strategy combination in which players are **not willing** to change their state. But this is quite informal: what does it rationally mean that a player does not want to change his state? In the Homo Economicus model, this makes sense when he has selected a strategy that maximizes his *individual wealth*, knowing that other players are also doing the same.

Roadmap

- We will focus on two prominent types of equilibria: Nash Equilibria (NE) and Dominant Strategy Equilibria (DSE)
- Computational Aspects of Nash Equilibria
  - Can a NE be feasibly computed, once it exists?
  - What about the "quality" of a NE?
  - Case study: Network Flow Games (i.e., selfish routing in Internet), Network Design Games, Network Creation Games
- (Algorithmic) Mechanism Design
  - Which social goals can be (efficiently) implemented in a strategic distributed system?
  - Strategy-proof mechanisms in DSE: Vickrey-Clarke-Groves (VCG)-mechanisms and one-parameter mechanisms
  - Case study: Shortest Path, Minimum Spanning Tree, Single-source Shortest-path Tree, Single-Minded Combinatorial Auctions