



A TWENTY-YEAR RETROSPECTIVE ON THE PRICE OF ANARCHY

<https://20poa.github.io>

WORKSHOP PROGRAM AND BOOK OF ABSTRACTS



Funded by the Horizon 2020 Framework Programme
of the European Union



INVITED SPEAKERS

Giorgos Christodoulou	(U. Liverpool)
Elias Koutsoupias	(U. Oxford)
Christos Papadimitriou	(Columbia U.)
Tim Roughgarden	(Columbia U.)
Eva Tardos	(Cornell U.)

Vittorio Bilò	(U. Salento)
Philip Brown	(U. Colorado)
Bo Chen	(U. Warwick)
Roberto Cominetti	(U. Adolfo Ibañez)
Bart De Keijzer	(U. Essex)
Diodato Ferraioli	(U. Salerno)
Aris Filos-Ratsikas	(EPFL)
Martin Gairing	(U. Liverpool)
Vasilis Gkatzelis	(Drexel U.)
Nikolai Gravin	(ITCS, U. Shanghai)
Tobias Harks	(U. Augsburg)
Martin Hoefer	(Goethe U. Frankfurt)
Max Klimm	(Humboldt U. Berlin)
Brendan Lucier	(Microsoft Research)
Rolf Möhring	(TU Berlin and U. Hefei)
Evdokia Nikolova	(UT Austin)
Guido Schäfer	(CWI Amsterdam)
Marc Schröder	(RWTH U. Aachen)
Alkmini Sgouritsa	(MPI)
Tristan Tomala	(HEC Paris)

PROGRAM AT A GLANCE

	TUE, JULY 2	WED, JULY 3	THU, JULY 4	FRI, JULY 5
10:00 – 11:00	C. Papadimitriou	G. Christodoulou	T. Roughgarden	E. Koutsoupias
11:00 – 11:30	<i>Coffee break</i>	<i>Coffee break</i>	<i>Coffee break</i>	<i>Coffee break</i>
11:30 – 11:55	T. Harks	R. Cominetti	B. De Keijzer	V. Bilò
11:55 – 12:20	G. Schäfer	R. Möhring	E. Nikolova	M. Gairing
12:20 – 12:45	A. Filos-Ratsikas	M. Schröder	T. Tomala	M. Hoefer
12:45 – 15:00	<i>Lunch break</i>	<i>Lunch break</i>	<i>Lunch break</i>	<i>Lunch break</i>
15:00 – 16:00	E. Tardos	FLASH TALKS S. Boodaghians V. Dose P. Lazos E. Macault B. Monnot M. Quattropani A. Tsikiridis A. Voudouris	DISCUSSION SESSION	N. Gravin G. Piliouras
16:00 – 16:30	<i>Coffee break</i>	<i>Coffee break</i>	<i>Coffee break</i>	Conference ends
16:30 – 16:55	B. Chen		M. Klimm	
16:55 – 17:20	D. Ferraioli	POSTER SESSION	B. Lucier	
17:20 – 17:45	V. Gkatzelis		A. Sgouritsa	

WELCOME FROM THE ORGANIZING COMMITTEE

It is our great pleasure to welcome you to Chania for the Twenty-Year Retrospective Workshop on the Price of Anarchy (PoA20)! We hope you will enjoy both the exciting technical program of the event as well as the beautiful island of Crete in July.

The purpose of this meeting is to bring together students, researchers and practitioners that are active in the broad area of algorithmic game theory, and to create a fertile forum for presenting research results, exchanging ideas, and initiating collaborations. As organizers, we hope there will be more to come in the future, and that this will be the first of many retrospectives on the subject.

This meeting is organized by GAMENET (<https://gametheorynetwork.com>), a COST action (CA 16228) which aims to be the European network for game-theoretic research. COST (European Cooperation in Science and Technology) is a pan-European intergovernmental framework whose mission is to enable break-through scientific and technological developments leading to new concepts and products and thereby contribute to strengthening Europe's research and innovation capacities (for more information, see www.cost.eu).

We are likewise grateful to our academic and industrial sponsors, as listed on the cover of this booklet: the French National Research Agency (ANR) that provided generous financial support through the JCJC project ORACLESS; the French National Center for Scientific Research (CNRS); the Gaspard Monge Programme for Optimization (PGMO) and its industrial sponsors, EDF, Orange, and Thales; and, last but not least, the administrative staff of our institutions for their valuable time and support in organizing this event.

This retrospective is bringing together more than 50 researchers and practitioners from all over the globe. Invited talks have been organized into 5 one-hour keynotes and 7 sessions, each consisting of 3 presentations. In addition to these sessions, there will be a poster session on Wednesday afternoon, preceded by a teaser session where each poster presenter will give a short outline of their work.

All talks will be taking place at the Electrical and Computer Engineering Department of the Technical University of Crete - we are very grateful to TUC and the local team of volunteers for their help and hospitality!

On behalf of the organizing committee, we wish you an exciting conference and a great time in Chania!

Ioannis Caragiannis	(University of Patras)
Georgios Chalkiadakis	(Technical University of Crete)
Vangelis Markakis	(Athens University of Economics and Business)
Panayotis Mertikopoulos	(CNRS)
Georgios Piliouras	(Singapore University of Technology and Design)
Marco Scarsini	(LUISS)

Tuesday, July 2

MORNING KEYNOTE (10:00 – 11:00)

Christos Papadimitriou

10:00 – 11:00

Data, Incentives and Fairness

MORNING TALKS (11:30 – 12:45)

Tobias Harks

11:30 – 11:55

Pricing in Resource Allocation Games

I will present a basic resource allocation game, where the players' strategy spaces are subsets of \mathbb{R}^m and cost/utility functions are parameterized by some common vector $u \in \mathbb{R}^m$ and, otherwise, only depend on the own strategy choice. A strategy of a player can be interpreted as a vector of resource consumption and a joint strategy profile naturally leads to an aggregate consumption vector. I assume that resources can be priced, that is, the game is augmented by a price vector $\lambda \in \mathbb{R}_+^m$ and players have quasi-linear overall costs/utilities meaning that in addition to the original costs/utilities, a player needs to pay the corresponding price per consumed unit. I investigate the following question: for which aggregated consumption vectors u can we find prices λ that induce an equilibrium realizing the targeted consumption profile? For answering this question, I sketch a duality-based framework and derive a characterization of the existence of such u and λ . It is shown that the characterization can help to unify some parts of largely independent streams in the literature.

Guido Schäfer

11:55 – 12:20

Price of Anarchy and its Relatives: It Is all About Perception

We survey recent results on the price of anarchy and its relatives of strategic games with players exhibiting "complex" preferences. Such games have recently been studied intensively to obtain a better understanding of the impact of altruistic or spiteful behavior, complex social relationships, risk-aversion in uncertain environments, different degrees of player responsiveness, the imposition of taxes in network games, etc. The obtained insights are often surprising or counterintuitive. For example, for congestion games the price of anarchy actually gets worse as players become more altruistic, while it improves as players care less about the congestion caused by others. Conceptually, such "complex games" can be viewed as being derived from a base game through suitable

modifications of the players' utility functions. Exploiting the relationship between the base game and the complex game is often key to derive tight bounds on the price of anarchy and still not well-understood for several fundamental games. This also connects to the intriguing question of how to "design" the utility functions of the players to arrive at good equilibria.

Aris Filos-Ratsikas

12:20 – 12:45

The Pareto Frontier of Inefficiency in Mechanism Design

We study the trade-off between the Price of Anarchy (PoA) and the Price of Stability (PoS) in mechanism design, in the prototypical problem of unrelated machine scheduling. We give bounds on the space of feasible mechanisms with respect to the above metrics, and observe that two fundamental mechanisms, namely the First-Price (FP) and the Second-Price (SP), lie on the two opposite extrema of this boundary. Furthermore, for the natural class of anonymous task-independent mechanisms, we completely characterize the PoA/PoS Pareto frontier; we design a class of optimal mechanisms that lie exactly on this frontier. In particular, these mechanisms range smoothly, with respect to parameter $\alpha \geq 1$ across the frontier, between the First-Price and Second-Price mechanisms. En route to these results, we also provide a definitive answer to an important question related to the scheduling problem, namely whether non-truthful mechanisms can provide better makespan guarantees in the equilibrium, compared to truthful ones. We answer this question in the negative, by proving that the Price of Anarchy of all scheduling mechanisms is at least n , where n is the number of machines.

AFTERNOON KEYNOTE (15:00 – 16:00)**Éva Tardos**

15:00 – 16:00

*Learning in Games***AFTERNOON TALKS (16:30 – 17:45)****Bo Chen**

16:30 – 16:55

Price of Fairness in Machine Scheduling Problems

Motivated by the notion of price of anarchy, we investigate the concept of price of fairness in resource allocation and apply it to two-agent single-machine scheduling problems, in which two agents, each having a set of jobs, compete for use of a single machine to execute their jobs. We consider the situation where one agent aims at minimizing the total of the completion times of his jobs, while the other seeks to minimize the maximum tardiness with respect to a common due date for her jobs. We first explore and propose a definition of utility, then we study both max-min and proportionally fair solutions, providing a tight bound on the price of fairness for each notion of fairness. We extend our study further to the problem in which both agents wish to minimize the total of the completion times of their own jobs.

Diodato Ferraioli

16:55 – 17:20

Controlling Opinion Diffusion on Social Networks

Opinion diffusion is studied on social graphs where agents hold opinions from some discrete set and social pressure leads them to conform to the opinion manifested by neighbors. Within this setting, questions related to which extent a minority/majority can spread the opinion it supports to the other agents are considered. In particular, we show that in case of binary opinions, a large minority exists that can always become a majority, and a bare majority can converge to consensus. Not only, the sets of agents that enable these results can be computed by a polynomial-time algorithm. Interestingly, these results marksthe boundary of tractability, since the influence power of smaller set of agents is shown to depend on certain features of the underlying graphs, which are NP-hard to be identified. We also show the extent at which these results fail when extended to a setting with more than two available opinions per agent.

Based on works appeared at WINE 2015, WINE 2017, AAMAS 2017, IJCAI 2018 (Distinguished Paper), AAMAS 2019.

Vasilis Gkatzelis

17:20 – 17:45

From Coordination Mechanisms to Approximation Algorithms in Selfish Scheduling

We focus on a selfish scheduling setting, where each player owns a job that needs to be processed by one of the available machines. Each player chooses which machine to schedule his job on, aiming to minimize its completion time, and our goal is to design local scheduling policies (or coordination mechanisms) that minimize the weighted sum of completion times across jobs in equilibrium. Our first set of results, which appeared at STOC '11, analyzes three coordination mechanisms that yield potential games and achieve constant price of anarchy bounds. We then discuss more recent results from WINE '17, which reveal a connection between coordination mechanisms and cost-sharing protocols. Using this connection, we interpret the aforementioned coordination mechanisms as Shapley-value-based cost-sharing protocols, providing a unifying justification regarding why these mechanisms induce potential games. More importantly, this connection enables the design of interesting approximation algorithms for the underlying optimization problem, translating price of anarchy bounds to approximation factors.

Wednesday, July 3

MORNING KEYNOTE (10:00 – 11:00)

G. Christodoulou

10:00 – 11:00

Price of Stability of (Weighted) Congestion Games

We will discuss results on the price of stability of congestion games. We will discuss both the unweighted and weighted version of the problem. In the latter we will discuss exponential lower bounds for the case of polynomial cost functions. Our results close the previous huge gap between $\Theta(d)$ and $O((d/\log d)^d)$ and almost matches the price of anarchy upper bound for polynomial latencies of degree d . On the positive side, we give a general upper bound on the price of stability of approximate Nash equilibria, which is sensitive to the range of the players' weights.

MORNING TALKS (11:30 – 12:45)

Roberto Cominetti

11:30 – 11:55

When Is Selfish Routing Bad? The Price of Anarchy in Light and Heavy Traffic

In this talk we examine the behavior of the Price-of-Anarchy (PoA) as a function of the traffic inflow in nonatomic routing games with multiple OD pairs. Empirical studies in real-world networks show that the PoA is close to 1 in both light and heavy traffic, thus raising the question: can these observations be justified theoretically?

We first show that this is not always the case: the PoA may remain a positive distance away from 1 for all values of the traffic inflow, even in simple three-link networks with a single OD pair and smooth, convex costs. On the other hand, for a large class of cost functions (including all polynomials), the PoA does converge to 1 in both heavy and light traffic, irrespective of the network topology and the number of OD pairs in the network. We also examine the rate of convergence of the PoA, and we show that it follows a power law whose degree can be computed explicitly when the network's cost functions are polynomials.

This talk is based on joint work with Riccardo Colini-Baldeschi, Panayotis Mertikopoulos, and Marco Scarsini.

Rolf Möhring

11:55 – 12:20

The Price of Anarchy Revisited: Selfish Routing Need Not Be Bad in High Congestion

We consider non-atomic congestion games with continuous and non-decreasing latency functions and investigate the limit of the price of anarchy (PoA) when the total user demand T approaches infinity. First results in this direction have recently been obtained by Colini-Baldeschi et al. and show that the PoA converges to 1 when the growth of the total demand T satisfies certain conditions. We extend their results substantially by developing a unified framework for the limit analysis of the PoA. Among others, we can show that the PoA converges to 1 regardless of the type of growth of T when all latency functions are polynomials. Our new techniques are very flexible and apply also to games with latency functions of other types. In addition, we analyze traffic networks with standard BPR latency functions and show a power law for the convergence speed of the PoA. We also report about a detailed empirical study with real traffic data of Beijing showing that the PoA is indeed 1, and already for a much reduced total user volume. The lecture is based on joint work with Zijun Wu, Yanyan Chen, and Dachuan Xu.

Marc Schröder

12:20 – 12:45

Price of Anarchy in Stochastic Atomic Congestion Games With Affine Costs

We consider an atomic congestion game with stochastic demand in which each player participates in the game with probability p , and incurs no cost with probability $1-p$. We assume that p is common knowledge among all players and that players are independent. For congestion games with affine costs, we provide an analytic expression for the price of anarchy as a function of p , which is monotonically increasing and converges to the well-known bound of $5/2$ as $p \rightarrow 1$. On the other extreme, for $p < 1/4$ the bound is constant and equal to $4/3$ independently of the game structure and the number of players. We show that these bounds are tight and are attained on routing games with purely linear costs. Additionally, we also obtain tight bounds for the price of stability for all values of p .

FLASH TALKS / POSTER SESSION (15:00 – 16:00 / 16:30 – 17:45)

Alexandros Voudouris

The efficiency of resource allocation mechanisms for budget-constrained users

Philip Lazos

The Pareto frontier of inefficiency in mechanism design

Matteo Quattropani

Existence and fairness of equilibria in the deterministic buck passing game

Valerio Dose

The price of anarchy as a function of the demand

Barnabé Monnot

Wealth inequality and the price of anarchy

Shant Boodaghians

Online revenue maximization for server pricing

Emilien Macaule

Learning in repeated routing games with symmetric incomplete information

Artem Tsikiridis

Tight welfare guarantees for pure Nash equilibria of the uniform price auction

Thursday, July 4

MORNING KEYNOTE (10:00 – 11:00)

Tim Roughgarden

10:00 – 11:00

Fair Division With Combinatorial Valuations: Complexity and Approximation

MORNING TALKS (11:30 – 12:45)

Bart de Keijzer

11:30 – 11:55

Altruism and its Impact on the Price of Anarchy

We study the inefficiency of equilibria for congestion games when players are (partially) altruistic. We model altruistic behavior by assuming that player i 's perceived cost is a convex combination of a_i times his direct cost and a_i times the social cost. Tuning the parameters a_i allows smooth interpolation between purely selfish and purely altruistic behavior. Within this framework, we study primarily altruistic extensions of (atomic and nonatomic) congestion games, but also obtain some results on fair cost-sharing games and valid utility games.

We derive (tight) bounds on the price of anarchy of these games for several solution concepts. Thereto, we suitably adapt the smoothness notion introduced by Roughgarden and show that it captures the essential properties to determine the robust price of anarchy of these games. Our bounds show that for atomic congestion games and cost-sharing games, the robust price of anarchy gets worse with increasing altruism, while for valid utility games, it remains constant and is not affected by altruism.

However, the increase in the price of anarchy is not a universal phenomenon: For general nonatomic congestion games with uniform altruism, the price of anarchy improves with increasing altruism. For atomic and nonatomic symmetric singleton congestion games, we derive bounds on the pure price of anarchy that improve as the average level of altruism increases. (For atomic games, we only derive such bounds when cost functions are linear.) Since the bounds are also strictly lower than the robust price of anarchy, these games exhibit natural examples in which pure Nash equilibria are more efficient than more permissive notions of equilibrium.

Evdokia Nikolova

11:55 – 12:20

Risk-Averse Selfish Routing

I will discuss what happens in a transportation network when travel times are uncertain and users who want to route between their respective sources and destinations are risk-averse. Inspired by the Price of Anarchy, I'll propose a measure of quantifying how much the degree of risk-aversion degrades the system performance (measured as the total expected delay of all users), separately from the effect of selfish routing choices of the users. I will conclude with the effect of user diversity on the quality of the resulting traffic equilibria, and specifically when diversity of user preferences improves outcomes in selfish routing.

Tristan Tomala

12:20 – 12:45

Efficiency of Correlation in a Bottleneck Game

We consider a model of bottleneck congestion in discrete time with a penalty cost for being late. This model can be applied to several situations where agents need to use a capacitated facility in order to complete a task before a hard deadline. A possible example is a situation where commuters use a train service to go from home to office in the early morning. Trains run at regular intervals, take always the same time to cover their itinerary, and have a fixed capacity. Commuters must reach their office in time. This is a hard constraint whose violation involves a heavy penalty. Conditionally on meeting the deadline, commuters want to take the train as late as possible. With the intent of considering strategic choices of departure, we model this situation as a game and we show that it does not have pure Nash equilibria. Then we characterize the best and worst mixed Nash equilibria, and show that they are both inefficient with respect to the social optimum. We then show that there exists a correlated equilibrium that approximates the social optimum when the penalty for missing the deadline is sufficiently large.

OPEN DISCUSSION

(15:00 – 16:00)

Townhall meeting

15:00 – 16:00

Open Problems, New Directions, and What the Future Holds

AFTERNOON TALKS (16:30 – 17:45)**Max Klimm**

16:30 – 16:55

The Continuous Network Design Problem

In the continuous network design problem, we are given a graph for which the latency of each edge depends on the ratio of the edge flow and the capacity installed. The goal is to find an optimal investment in edge capacities so as to minimize the sum of the routing costs of the induced Wardrop equilibrium and the investment costs for installing the edge capacities. We revisit a heuristic studied by Marcotte [P. Marcotte, Math. Prog. 1986] and give a closed form of its approximation guarantee for arbitrary latency functions that depends on the anarchy of the set of latency functions. We further propose another approximation algorithm and show that it has the same approximation guarantee. Finally, we show that using the better of the two approximation algorithm results in a strictly improved approximation guarantee for which we again give a closed form expression. For affine latencies, e.g., the best-of-two approach gives as 49/41-approximation improving on the factor of 5/4 that has been shown before by Marcotte.

Brendan Lucier

16:55 – 17:20

Reducing Inefficiency in Carbon Auctions With Large Firms

Motivated by emission license auctions, we study the social welfare of uniform price auctions for multiple identical items subject to a social cost of allocation. Due to the mixed-sign objective, the price of anarchy of such auctions can be unbounded, with demand reduction leading to possibly negative welfare at equilibrium. In this talk we will explore simple augmentations to the standard auction format that can help limit the impact of strategic manipulation.

Alkmini Sgouritsa

17:20 – 17:45

Resource-Aware Cost-Sharing Methods for Scheduling Games

We study the performance of cost-sharing protocols in a selfish scheduling setting with load-dependent cost functions. Previous work on selfish scheduling protocols has focused on two extreme models: omnipotent protocols that are aware of every machine and every job that is active at any given time, and oblivious protocols that are aware of nothing beyond the machine they control. The main focus of this paper is on a well-motivated middle-ground model of resource-aware protocols, which are aware of the set of machines that the system comprises, but unaware of what jobs are active at any given time. We provide protocols with dramatically improved price of anarchy compared to the oblivious ones. Apart from considering budget-balanced protocols, to which most of previous work was restricted, we augment the design space by also studying the extent to which overcharging can lead to improved performance.

Friday, July 5

MORNING KEYNOTE (10:00 – 11:00)

Elias Koutsoupias

10:00 – 11:00

Efficiency vs. Inequality

MORNING TALKS (11:30 – 12:45)

Vittorio Bilò

11:30 – 11:55

Price of Anarchy in Congestion Games With Priority-Based Scheduling

We consider congestion games in which players are partitioned into priority classes and resources schedule their users according to a priority-based ordering, breaking ties uniformly at random. This framework generalizes a model of strategic behaviour under uncertainty proposed by Piliouras et al (2016). We consider games with affine latency functions and risk-neutral players and prove that, for any number of priority classes, the price of anarchy can be upper bounded by the value of the optimal solution of a certain non-linear program. By building on one such solution, we also show how to construct games with singleton strategies and linear latencies exhibiting a matching price of stability.

Martin Gairing

11:55 – 12:20

Cost-Sharing in Weighted Congestion Games

This work studies the price of anarchy and the price of stability of cost-sharing methods in weighted congestion games. We require that our cost-sharing method and our set of cost functions satisfy certain natural conditions and we present general tight price of anarchy bounds, which are robust and apply to general equilibrium concepts. We then turn to the price of stability and prove an upper bound for the Shapley value cost-sharing method, which holds for general sets of cost functions and which is tight in special cases of interest, such as bounded degree polynomials. Also for bounded degree polynomials, we close with a somehow surprising result, showing that a slight deviation from the Shapley value has a huge impact on the price of stability. In fact, for this case, the price of stability becomes as bad as the price of anarchy.

Martin Hoefer

12:20 – 12:45

Strategic Payments in Financial Networks

In the standard model for systemic risk by Eisenberg and Noe, a number of financial institutions are embedded in a network of debt relations. We analyze this model from a game-theoretic perspective. Each institution strives to strategically allocate its remaining money to clear as much debt as possible. Depending on the permissible strategies for payments, we study existence of pure and/or strong equilibria. Moreover, we consider a notion of social welfare and provide bounds on prices of anarchy and stability.

AFTERNOON TALKS (15:00 – 16:00)**Nikolai Gravin**

16:30 – 16:55

PoA of Simultaneous Item Auctions and Bayesian Mechanism Design

Simultaneous item auctions are simple and practical procedures for allocating items to bidders with potentially complex preferences. In this auction format, the allocation and prices are resolved for each item separately, based solely on the bids submitted on that particular item. The efficiency of Bayes-Nash equilibrium (BNE) outcomes of simultaneous first- and second-price auctions when bidders have complement-free (a.k.a. subadditive) valuations is always a constant fraction of the expected welfare of the optimal allocation. Our proof techniques are different from the typical smoothness arguments and are related to the literature on Bayesian mechanism design. We will discuss these connections in the talk.

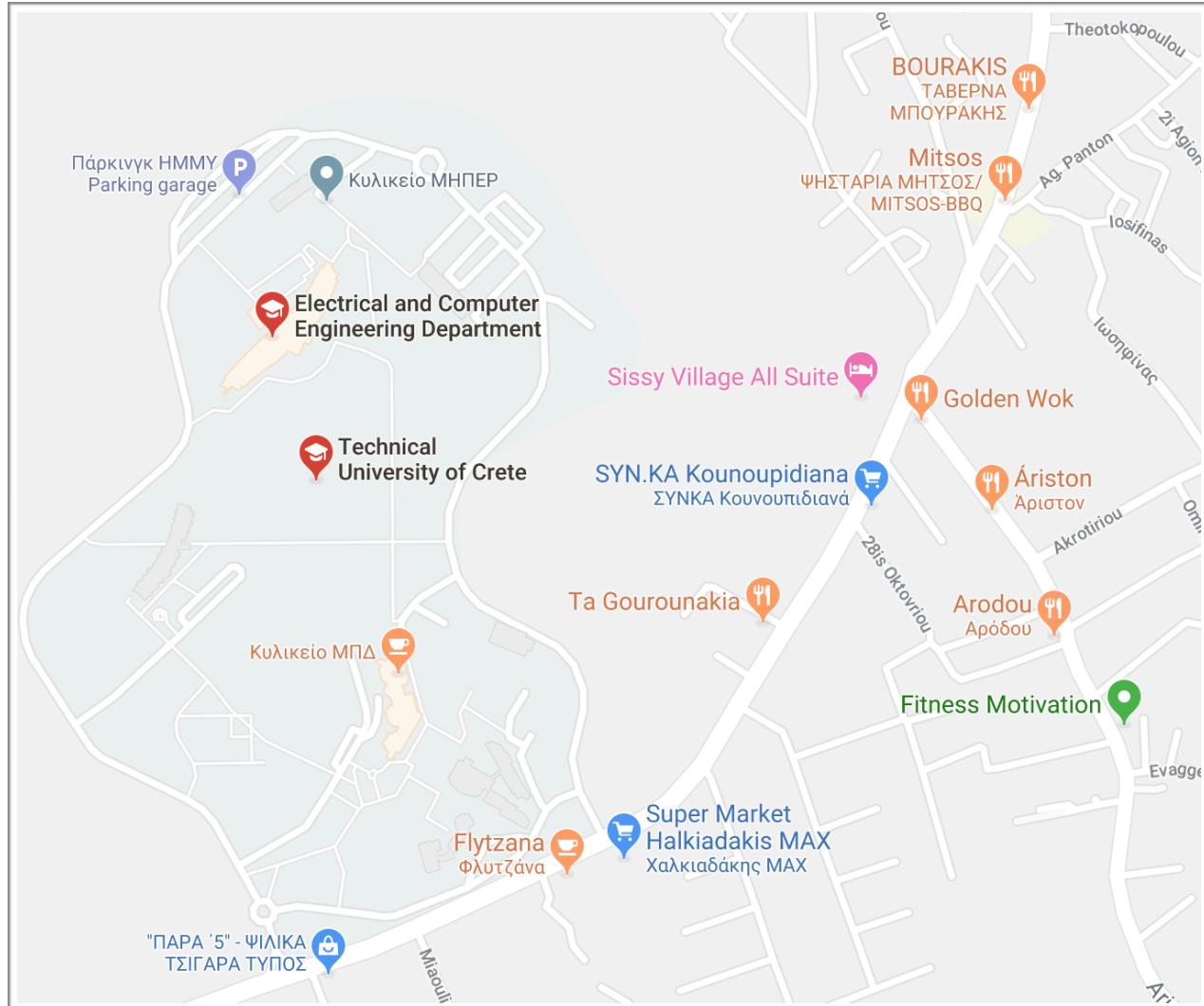
Georgios Piliouras

16:55 – 17:20

Coda and Closing Remarks

CONFERENCE VENUE

All talks will take place at the Electrical and Computer Engineering Department of the Technial University of Crete (see map below). The 20PoA workshop is colocated with the ACAI special course, and you can find a lot of information about the venue on the ACAI webpage (<http://acai2019.tuc.gr>) and the ACAI-2019 Facebook page.



If you need more flexibility on your transfers during your stay at Chania, you can book or call one of the local taxi services. Three of them: easytaxichania.gr, chaniataxi.gr, taxikydon.gr

We will have dedicated buses coming directly to the venue. Dedicated buses will display the line number 23, or occasionally 18 (which is the regular line to “Kounoupidiana”, the nearby municipality). Our volunteers will be available at departure points on Tuesday 02/07 to guide you; up-to-date information will be posted regularly on the conference webpage.

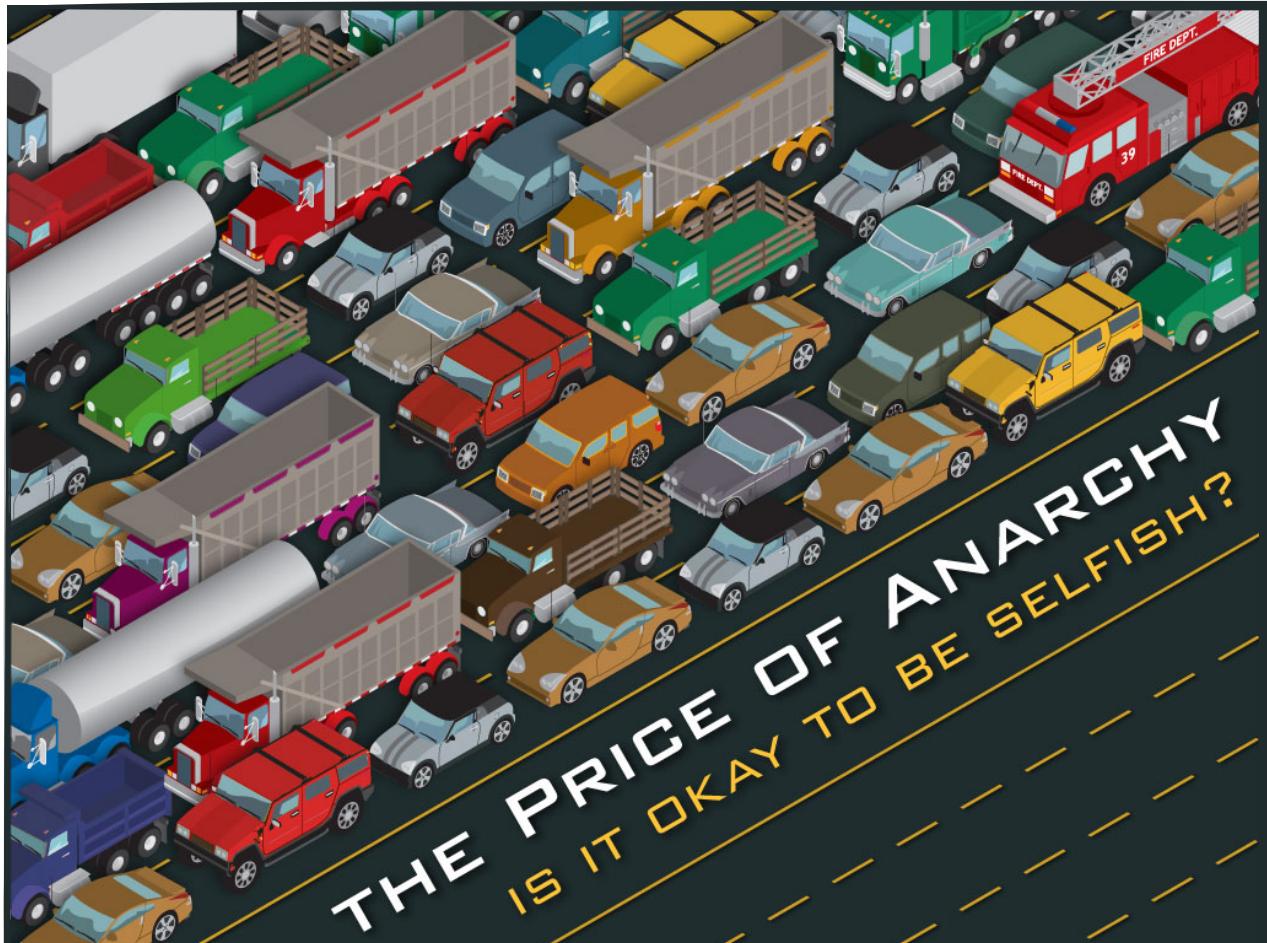


Image source: <https://thmatters.wordpress.com/the-price-of-anarchy/>



Funded by the Horizon 2020 Framework Programme
of the European Union

