Courtesy as a Means to Coordinate

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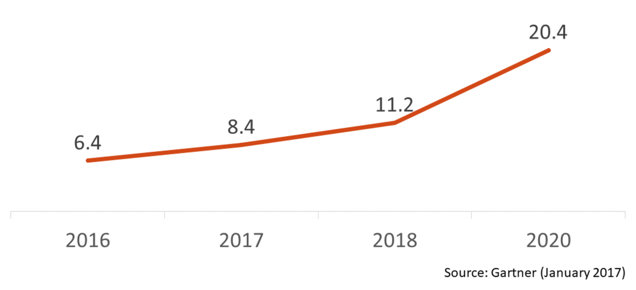
Motivation

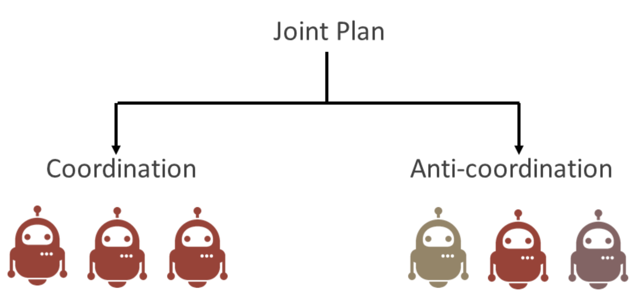
Intelligent Infrastructure:

- Smart homes / cities
- Connected IoT devices
- Autonomous vehicles
- Robotic agents / CPS

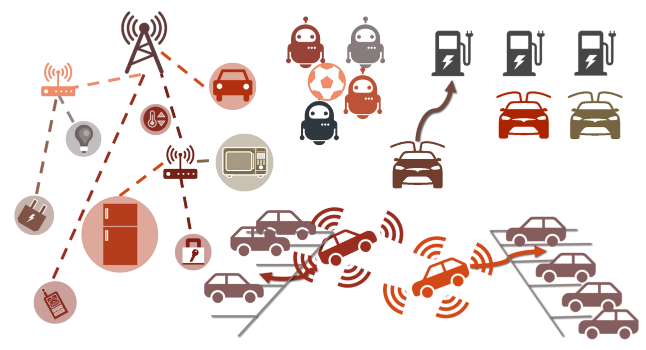
Projected #IoT Devices(bn):



Multi-agent Systems:



Applications:



Challenges:

- Large scale & distributed
- Information restrictive
- Diversify learning outcomes
- Strategic agents
- Efficiency & Fairness
- **Fast convergence**

Humans are able to *routinely* and *effortlessly* (anti-)coordinate in their daily lives in large scale and under dynamic and unpredictable demand. Key concept: use of **conventions** [1].

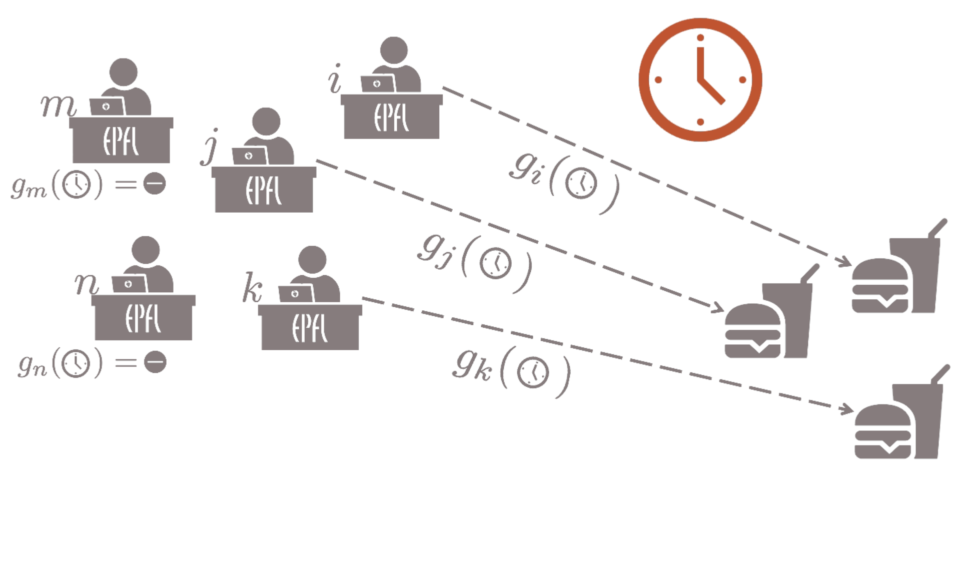
Infinitely Repeated (δ) Allocation Problem

$\mathcal{N}$ agents, $\mathcal{R}$ resources, $|\mathcal{N}| \gg |\mathcal{R}|$

$\mathcal{A} = \{Y, A_1, \dots, A_R\}$ actions

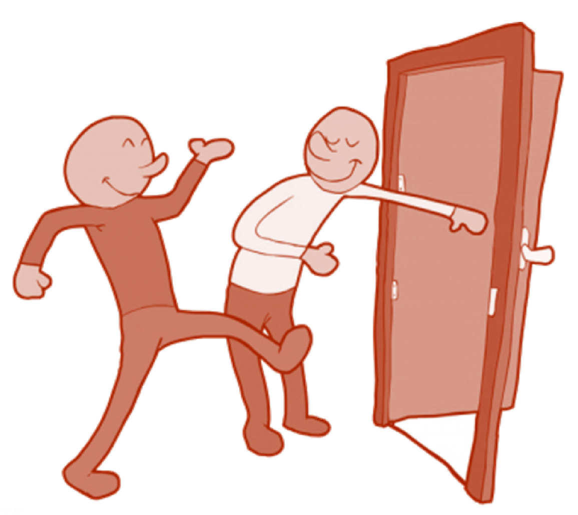
$$u_n(a_n, a_{-n}) = \begin{cases} 0, & \text{if } a_n = Y \\ 1, & \text{if } a_n \neq Y \wedge a_i \neq a_n, \forall i \neq n \\ \zeta < 0, & \text{otherwise} \end{cases}$$

Side information: **context**, $k \in \mathcal{K}$ (e.g. time, date etc.). Common signal in the agents' decision-making process; a means to learn and anti-coordinate their actions. No relation between the context space & the problem.



Proposed Framework (CA^{3}NONY)

CA^{3}NONY is founded on the *human-inspired* convention of courtesy. When contesting for a resource, there exist equilibrium back-off probabilities, but are hard to compute. Solution: do not compute them; be courteous (i.e. **positive back-off probability** in case of collision)! This allows for *fast convergence*, albeit it is not game theoretically sound; people adhere to it due to social pressure. Under scarcity of resources people exhibit urgency and competitive behavior [3]. Similarly, a rational agent could stubbornly keep accessing a resource forever ('bully' strategy [4]). To satisfy our rationality constraint we need a *deterrent mechanism*. CA^{3}NONY employs simple decentralized monitoring authorities (no planning, no knowledge of preferences), to keep track of successful accesses and align individual incentives.



Theorem 1 (Convergence Speed).

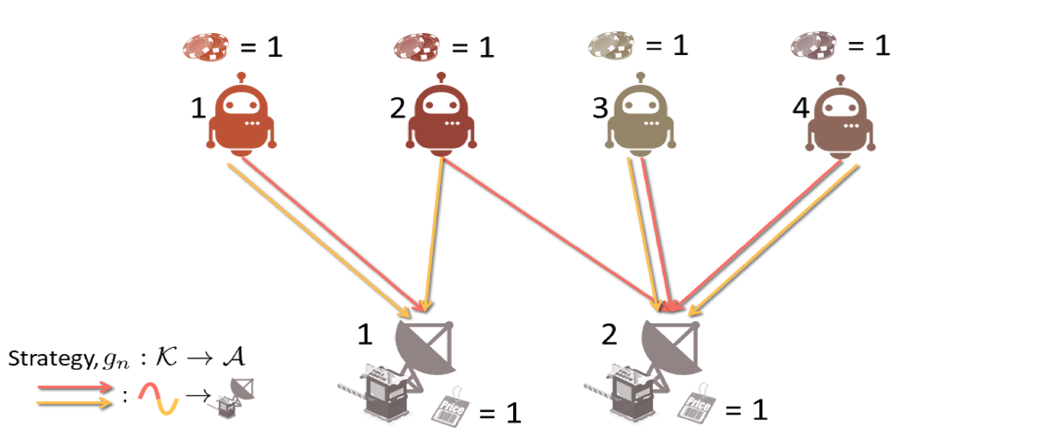
$$\mathcal{O}\left(N\left(\log\left\lceil\frac{N}{R}\right\rceil + 1\right)(\log N + R)\right)$$

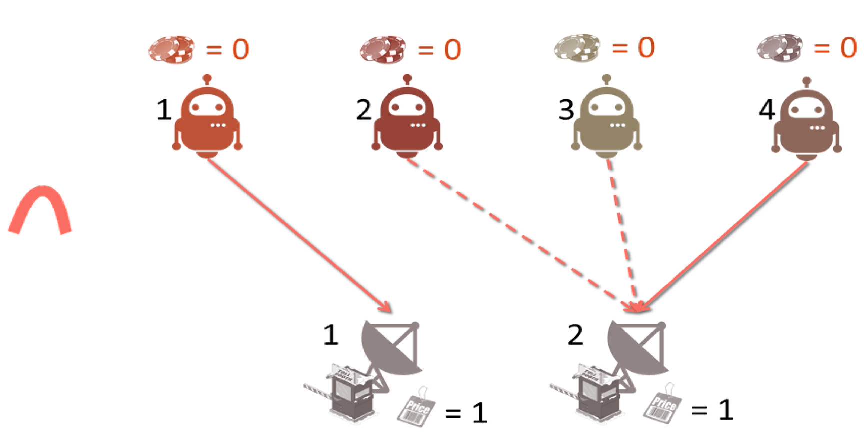
Theorem 2 (Rationality). *Under the CA^{3}NONY framework, courtesy induces strategies (σ_n^p) that constitute an approximate subgame-perfect equilibrium, i.e.*

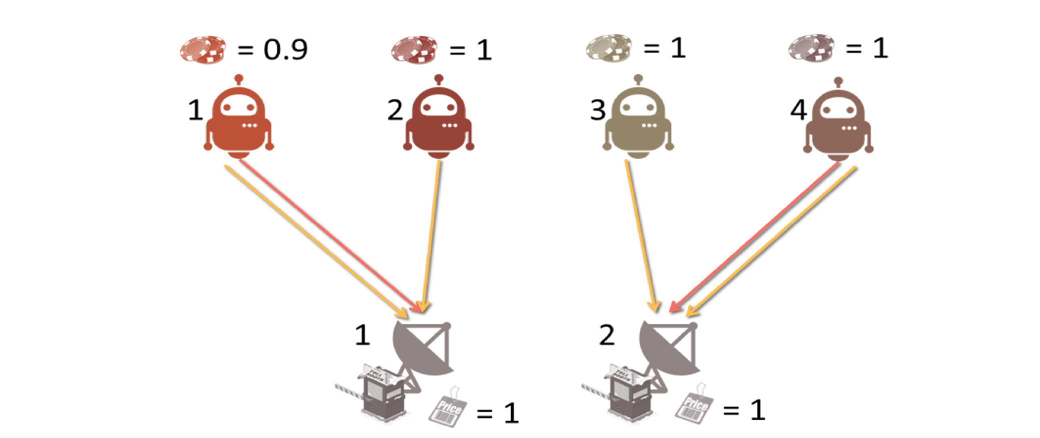
$$\mathbb{E}[U_n(\sigma_n^p, \sigma_{-n}^p, \delta)] > (1-\epsilon)\mathbb{E}[U_n(\sigma_n^*, \sigma_{-n}^p, \delta)]$$

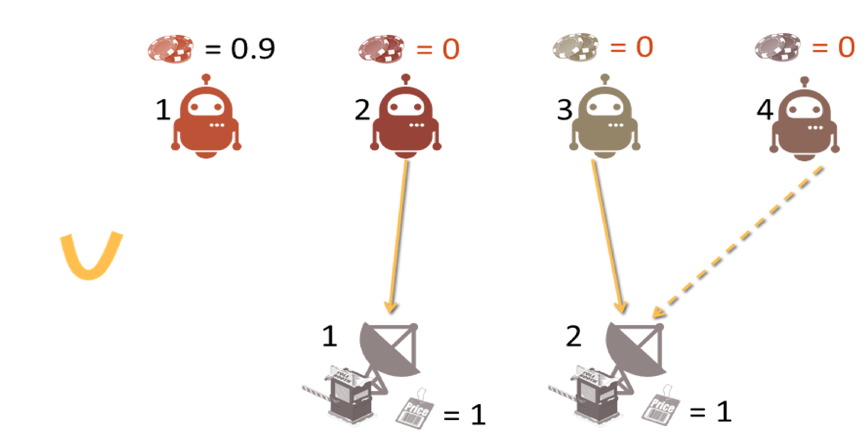
Example:

- $N = 4$, Agents
- $R = 2$, Channels (Identical & Indivisible)
- $K = 2$, Arbitrary Context
- $m = 1$, Artificial Cash & Price
  $\xi = 0.1$, Commission fee

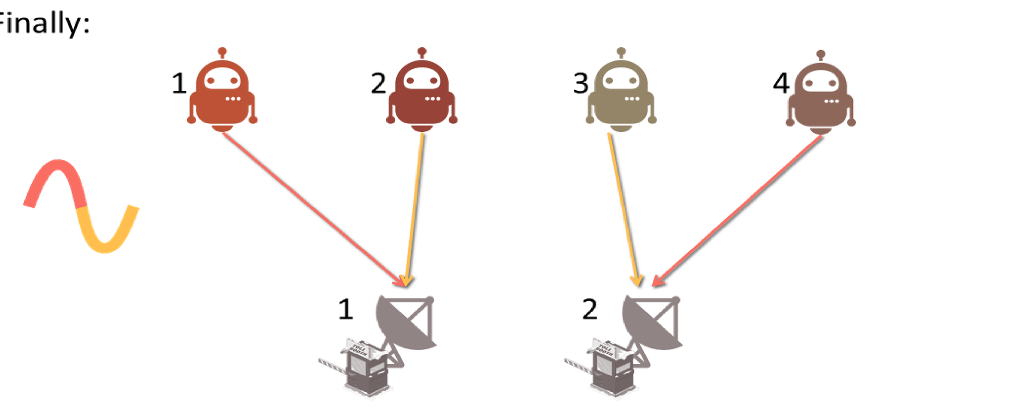




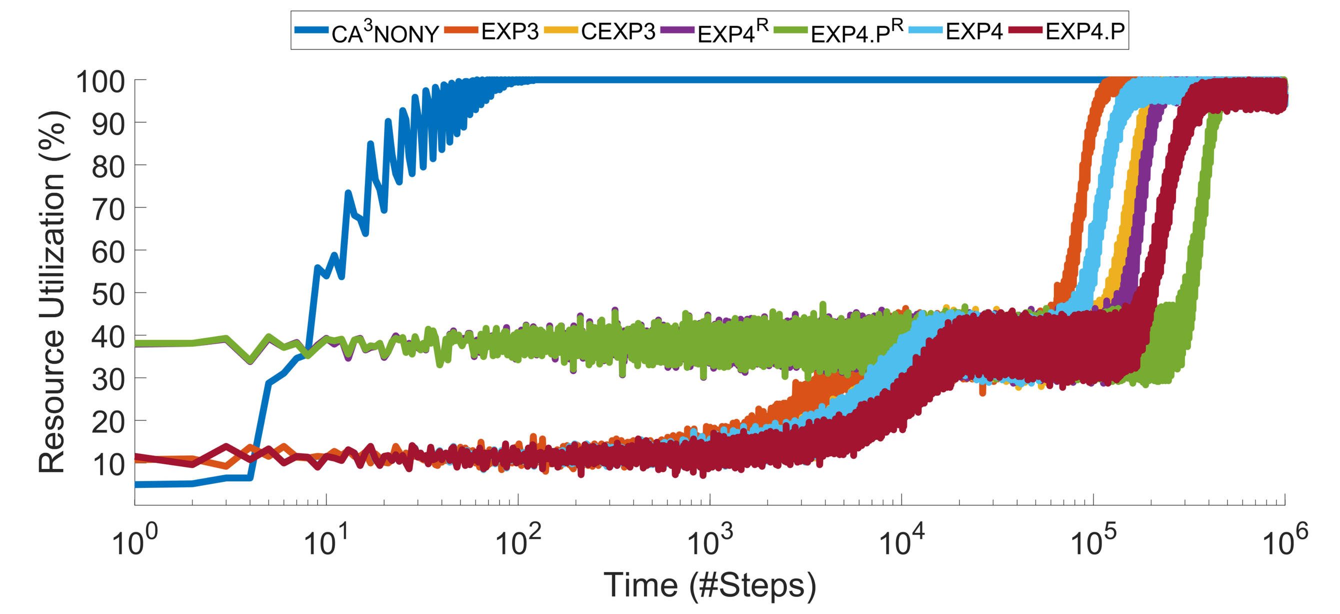


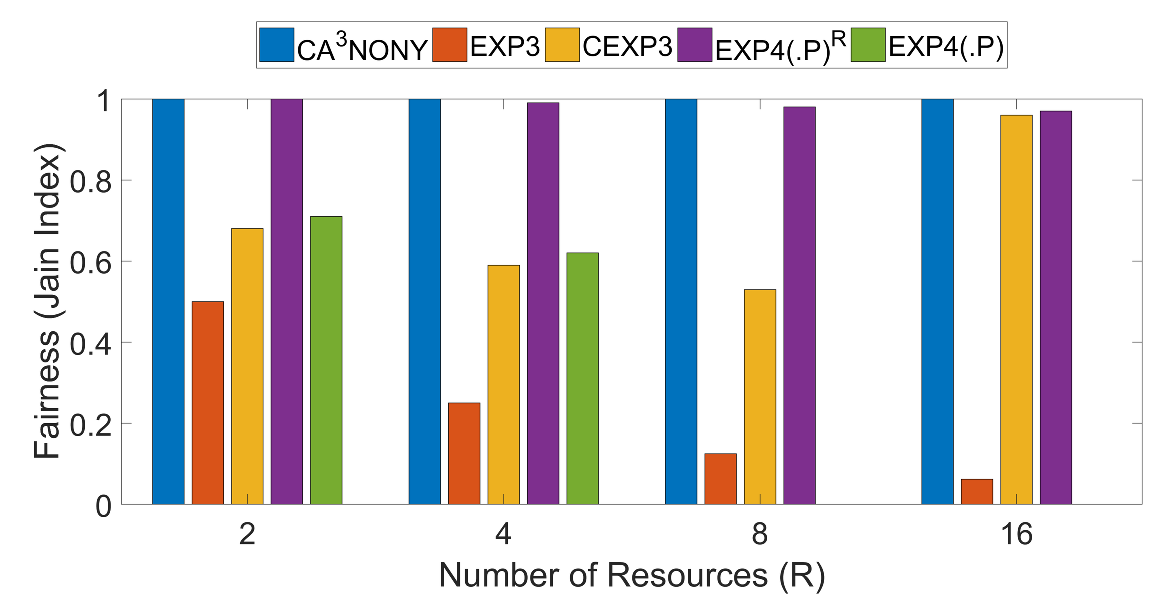


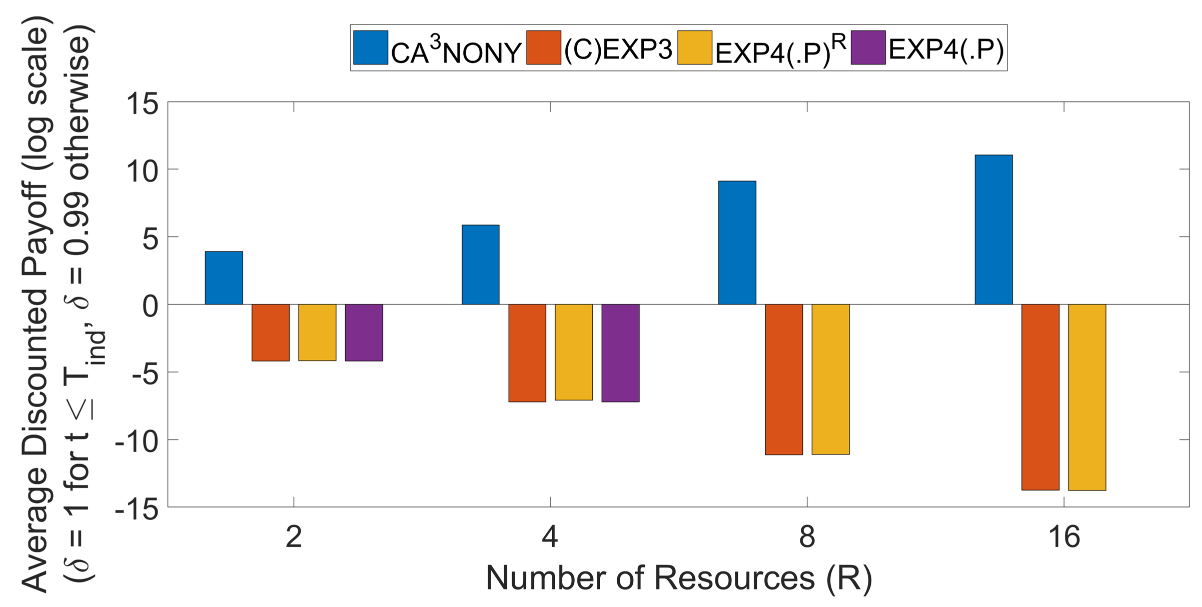
Finally:

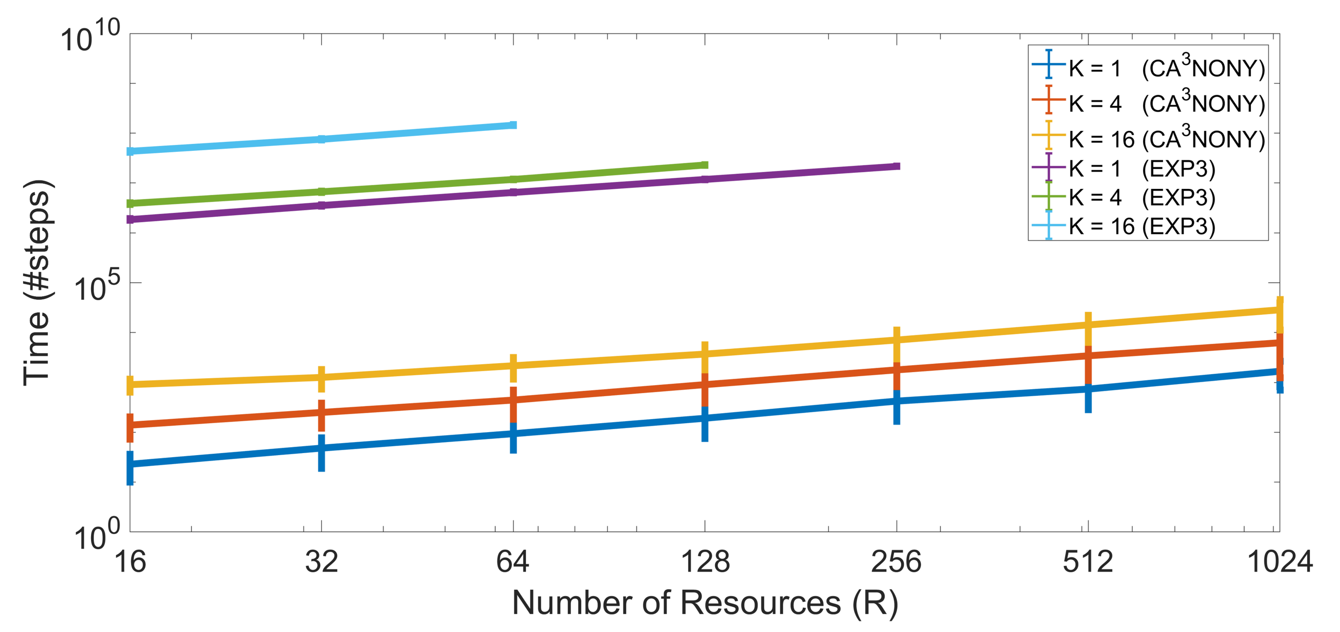


Simulation Results









References

[1] D. Lewis, *Convention: A philosophical study.* John Wiley & Sons, 2008.

[2] L. Cigler and B. Faltings, "Decentralized anti-coordination through multi-agent learning," *JAIR*, 2013.

[3] S. Gupta and J. W. Gentry, "The behavioral responses to perceived scarcity - the case of fast fashion," *The International Review of Retail, Distribution and Consumer Research*, 2016.

[4] M. L. Littman and P. Stone, *Implicit Negotiation in Repeated Games.* 2002.

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