Scalable Distributed Control of Network of DERs

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Large active network of DERs

	#nodes	capacity per node	total capacity	completion time	remarks
SCE	500	1 MW	500 MW	2015	SCE Commercial Rooftop Solar
CA	175,000	10 kW	1.75 GW	2016	CA Solar Initiative
SCE	400,000	2 kW	800 MW	--	10% penetration of SCE residential customers
CA	1,000,000	3 kW	3 GW	2017	CA Million Solar Roofs Initiative
CA	--	--	25 GW	2020	CA Renewable Portfolio Standard
US	--	--	3 TW	2035	Obama's goal for clean energy

DER: PVs, wind turbines, batteries, EVs, DR loads

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SCE					Rooftop
					ofs
CA					Portfolio
US	--			2035	Obama's goal for clean energy

Millions of active endpoints introducing rapid large random fluctuations in supply and demand

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Outline

Economic issues

- Distributed generation, interaction of different technology uptakes, business models
- Distribution market

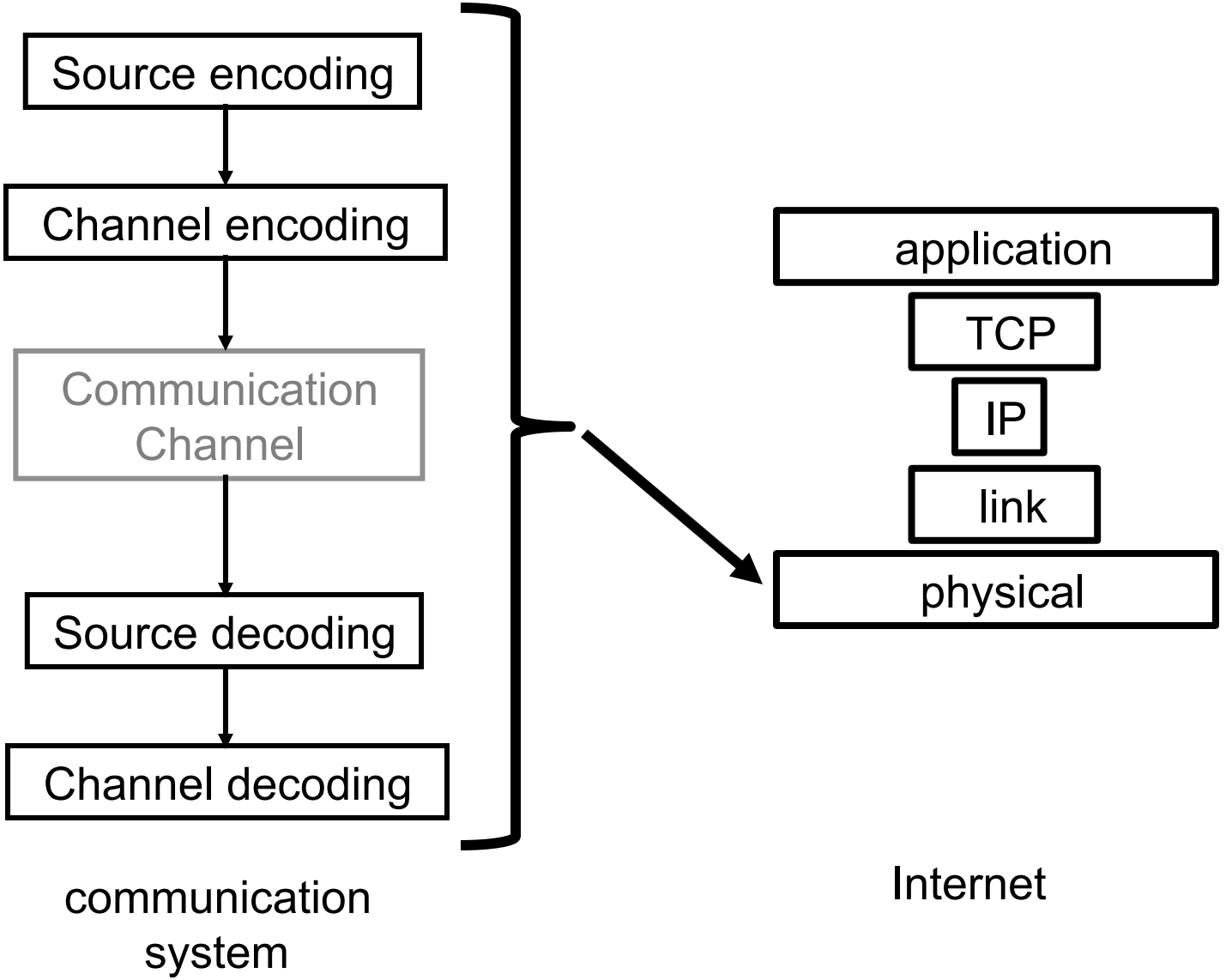
Engineering issues

- Key element: architecture
  - Some lessons from telephony → Internet
- Examples

Network Architecture

- Architecture is the single most important element that underlies Internet's explosive growth
  - Good architecture accelerates innovation, bad freezes it
- Yet, there is no formal theory nor systematic design principle for network architecture

Example architectures



Impact of Good Architecture

Internet has revolutionized communications, serving as a platform for innovation with impacts far beyond communications

Telephony

Music

TV & home theatre

Finding your way

Mail

Friends

Cloud computing

Library at your finger tip

Games

Elements of architecture

Layering as optimization decomposition

- Modularity, abstraction, evolvability

Constraints that deconstrain

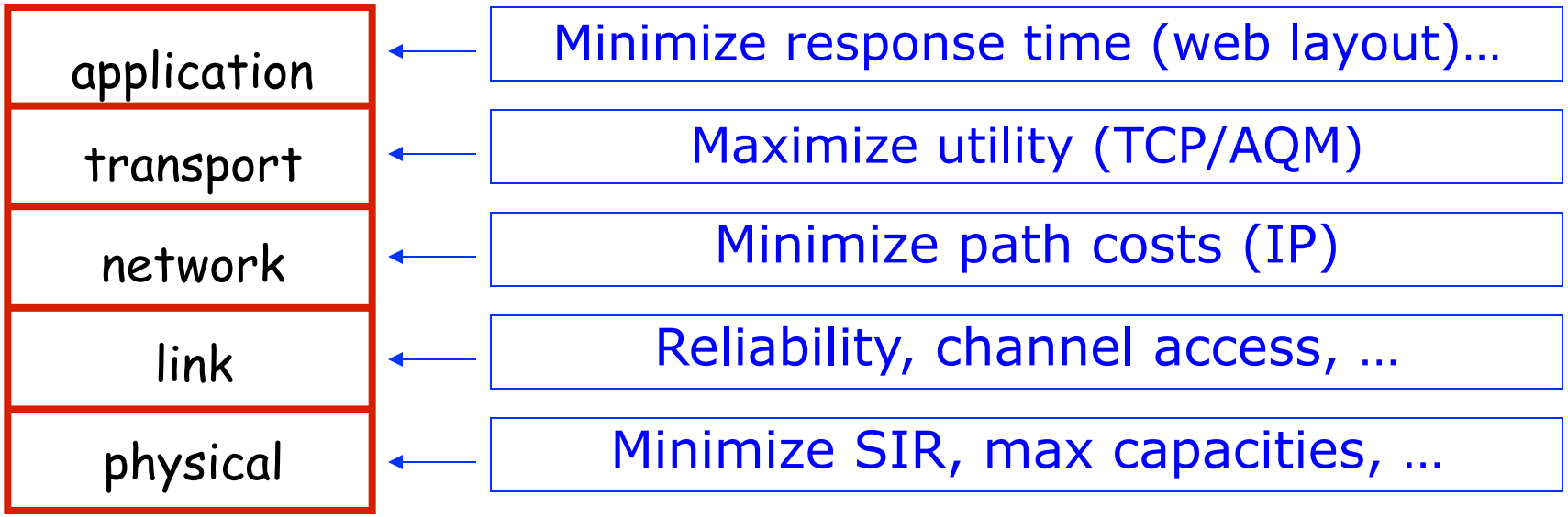
- Minimum set of constraints that free up design choices everywhere else

Robust yet fragile

- Careful tradeoffs of robustness against anticipated uncertainties with fragility elsewhere

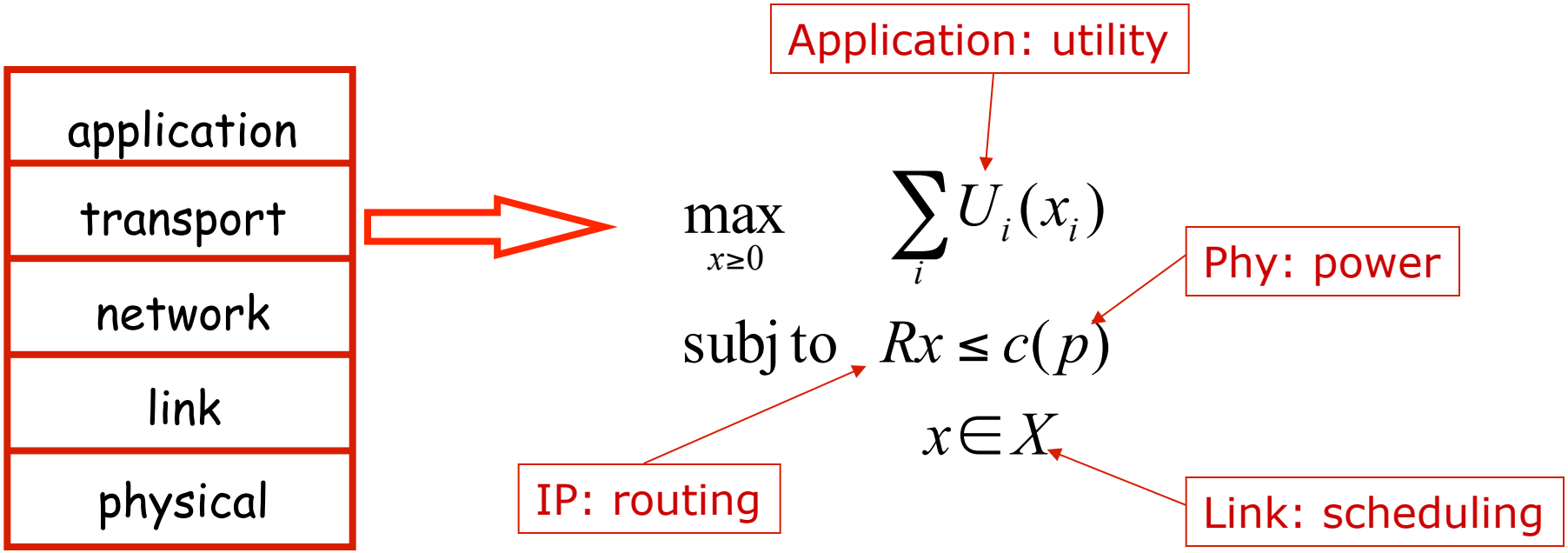
Layering as optimization decomposition

- Each layer designed separately and evolves asynchronously
- Each layer optimizes certain objectives



Layering as optimization decomposition

- Each layer is abstracted as an optimization problem
- Operation of a layer is a distributed solution
- Results of one problem (layer) are parameters of others
- Operate at different timescales



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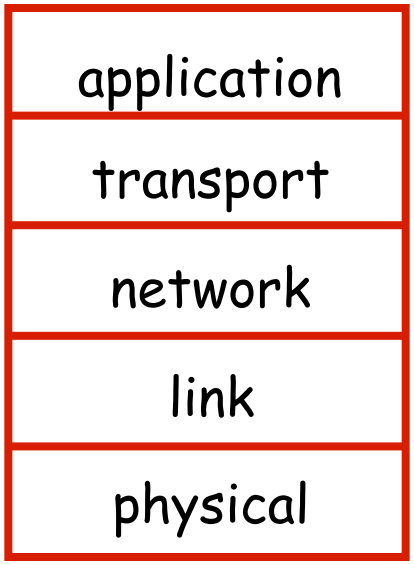
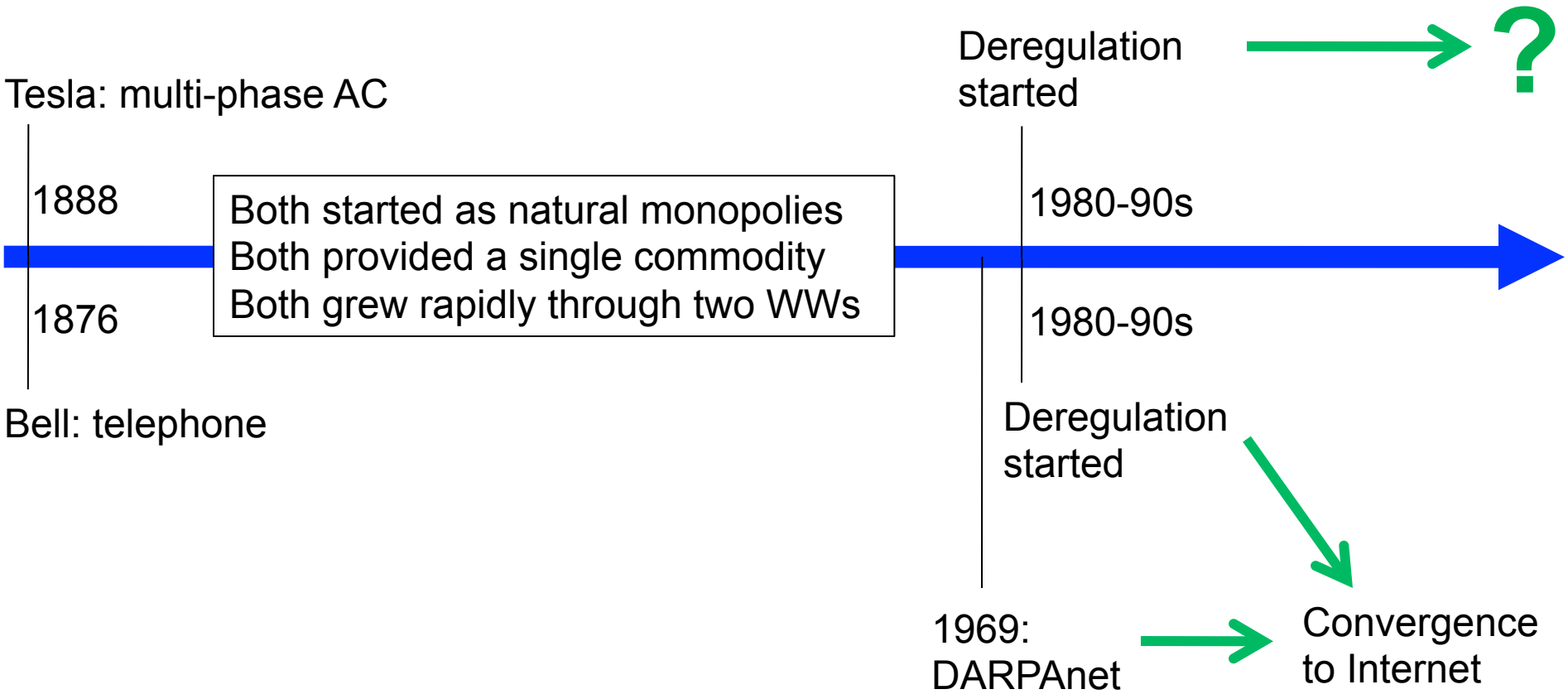


- Network — global optimization problem
- Layers — subproblems
- Layering — decomposition methods
- Interface — functions of primal or dual vars

But …. (caveat)

Watershed moment

Power network will undergo similar **architectural transformation** that phone network went through in the last two decades



Differences … lots of them

Need for extreme reliability

- Similar to telephony
- But many sectors that can benefit from less

Huge capital investment, long lifetime

- Simple and stable core, intelligent periphery
- Telephony vs Internet

Cyber-physical system

- Physical laws that cannot be designed away
- Abstractions/device breakthroughs that insulate higher layer design from physics ?

Lessons from Internet

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Implications

Current control paradigm works well today

- Centralized, open-loop, human-in-loop, worst-case preventive
- Low uncertainty, few active assets to control
- Schedule supplies to match loads

Future needs

- Closing the loop, e.g. real-time DR, Volt/VAR control, EV/storage mgt
- Fast computation to cope with rapid, random, large fluctuations in supply, demand, voltage, freq
- Simple algorithms to scale to large networks of active DER

Our focus: control & optimization

Different applications

- Distributed Volt/VAR control
- PEV charging coordination
- Large-scale real-time demand response
- Economic dispatch, unit commitment

Different timescales

- Seconds
- Minutes
- Hours

Interactions between algorithms across timescales

Our approach

Endpoint based control

- Self-manage through local sensing, communication, control
- Real-time, scalable, closed-loop, distributed, robust

Local algorithms with global perspective

- Holistic framework with global objectives
- Decompose global objectives into local algorithms

Control and optimization framework

- Theoretical foundation for a holistic framework that integrates engineering + economics
- Systematic algorithm design
- Understandable global behavior

Key technical challenges

Nonconvexity

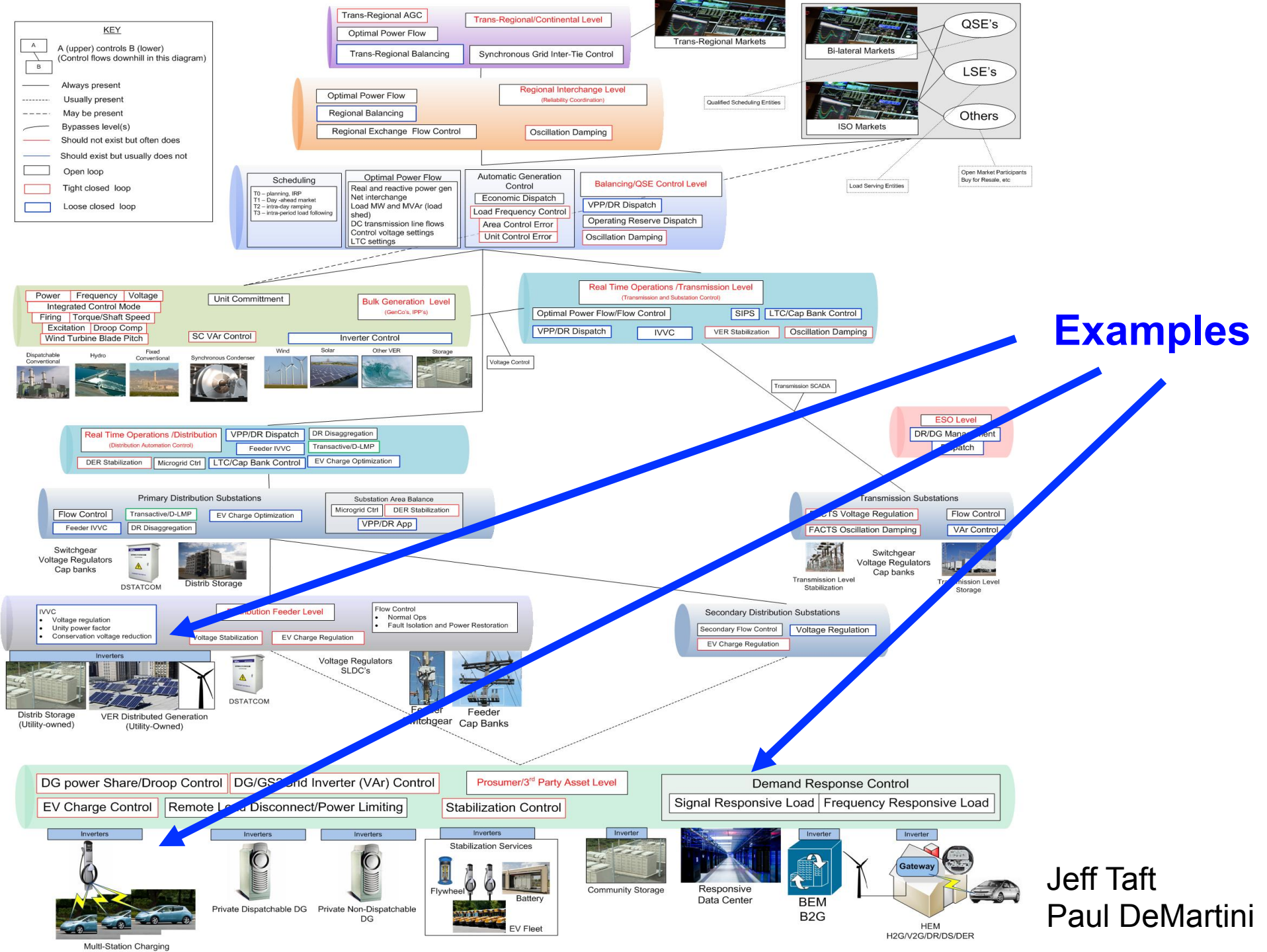
- Convex relaxations

Large scale

- Distributed algorithms

Uncertainty

- Risk-limiting approach



Examples

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