SATISFIABILITY OF ELASTIC DEMAND IN THE SMART GRID

Jean-Yves Le Boudec,
Joint work with Dan-Cristian Tomozei
EPFL

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ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Contents

[arXiv:1011.5606v1] Jean-Yves Le Boudec and Dan-Cristian Tomozei
« Satisfiability of Elastic Demand in the Smart Grid », Nov 2010, arxiv.org

The Swiss Dream…

The goal: the 2000-Watt Society.
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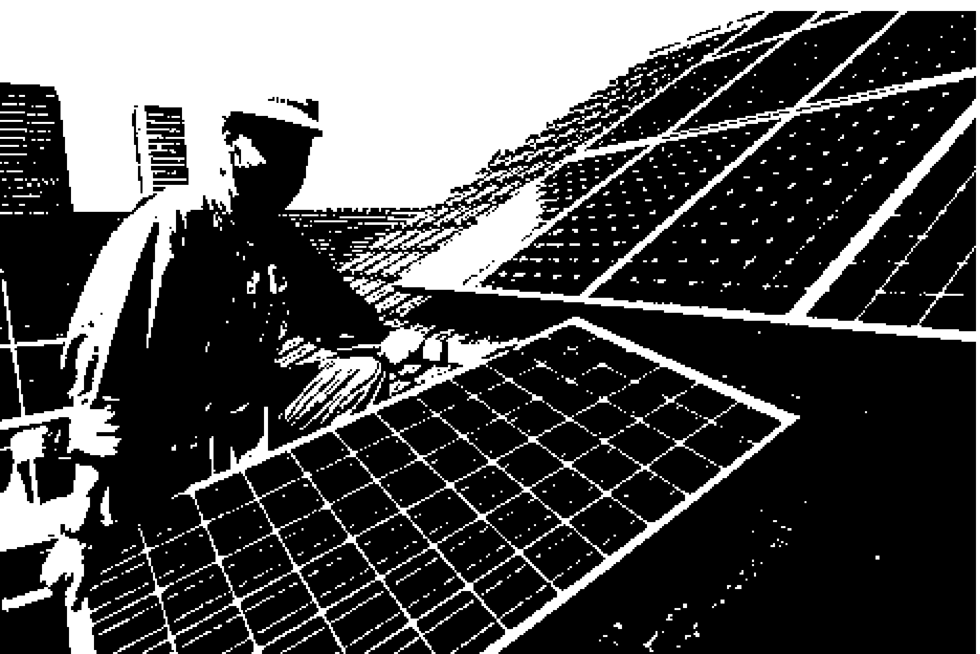
- 2000 W society = energy expenditure per capita as it was in 1960 in Western Europe

  (in CH; = 63.1 GJ per year per capita)

- Today: 5000 – 6000 W

- Realistic Goal for 2050: 3500 W
  [*The 2000 Watt Society –Standard or Guidepost?* Energiespiegel Nr 18, April 2007, PSI, Switzerland]



The British Dream…

	Watts	kWh/d
Swiss dream	2000	48
Today CH	6000	144
2050 CH	3500	84
MacKay's model UK	5200	125
2050 UK	2833	68
2008 UK grid	750	18
2050 UK grid	2000	48

- David MacKay 2009 « Sustainable Energy without the Hot Air »
- An aggressive, though not unrealistic plan requires ca 3000W,
  ¾ of which is by the electrical grid

Solar power could crash Germany's grid

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HARNESSING the sun's energy could save the planet from climate change, an approach that Germany has readily adopted. Unfortunately, this enthusiasm for solar panels could overload the country's ageing electricity grid.

Solar power is intermittent and can arrive in huge surges when the sun comes out. These most often happen near midday rather than when demand for power is high, such as in the evenings. A small surge can be accommodated by switching off conventional power station generators, to keep the overall supply to the grid the same. But if the solar power input is too large it will exceed demand

Too much of a good thing? (Image Patrik Stollarz/AFP/Getty)

- Volatility in demand
- Increased volatility in supply

- Calls for intelligent demand and supply

« Adaptive Appliances »

Management of Energy Demand

- *Managing End-User Preferences in the Smart Grid,* C. Wang and M. d. Groot, E-energy 2010, Passau, Germany, 2010

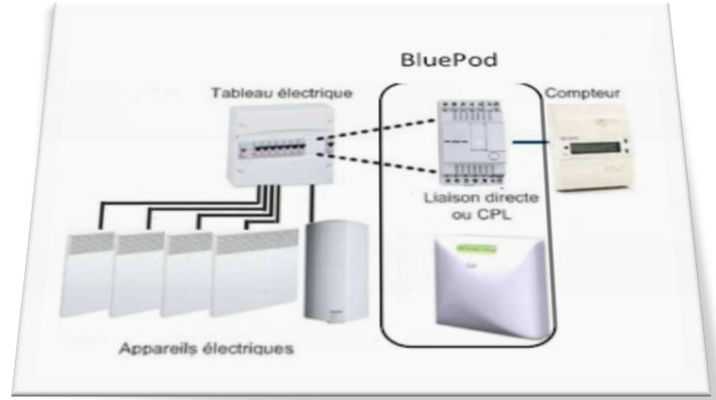


Table 1: Example User Preference Matrix

Appliance	Preference	$t_0 - t_1$	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$
a_0	1	1kW			
	2		1kW		
	3			1kW	
a_1	1	2kW	2kW	2kW	2kW
	2	2kW		2kW	
	3	1kW	1kW	1kW	1kW

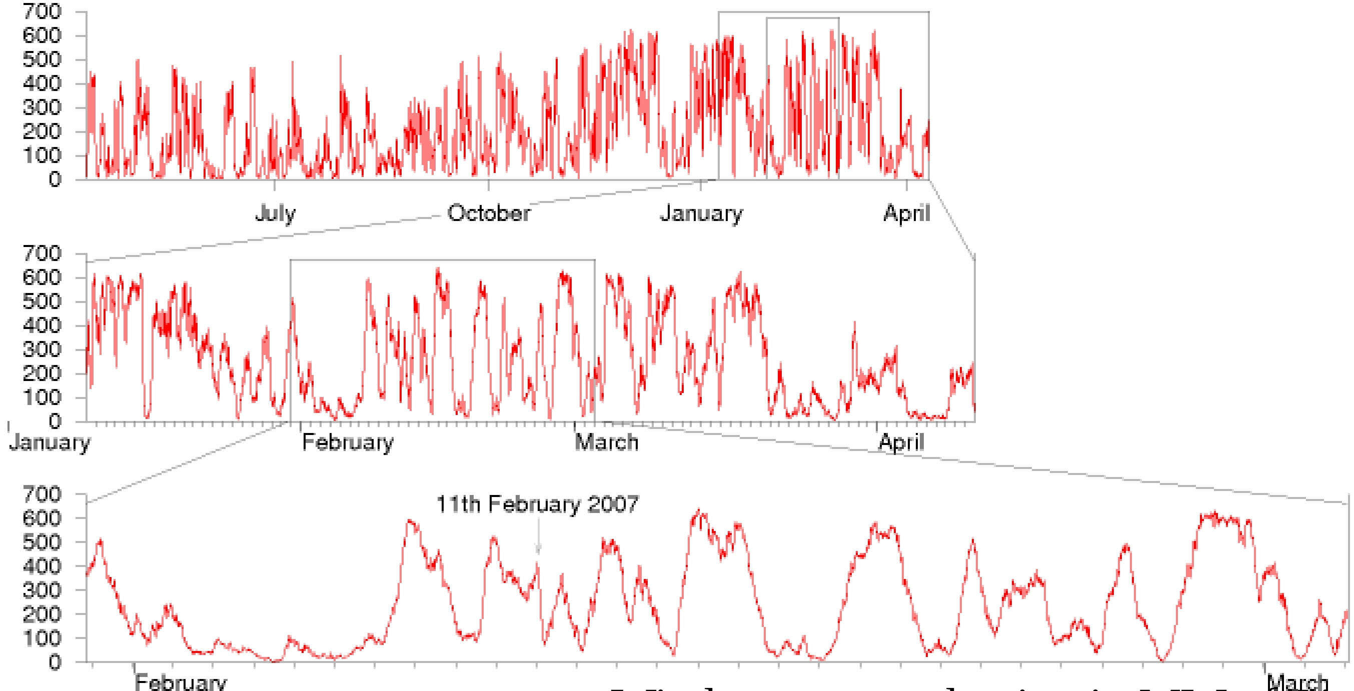
VOLTALIS
The e-power company

- Demand response by load switch
- For thermal load www.voltalis.com

Beyond Demand Response

- Demand response = shave the peak
  mean does not adapt

- Tomorrow (2050)
  adapt to wind, tidal, solar etc over several days

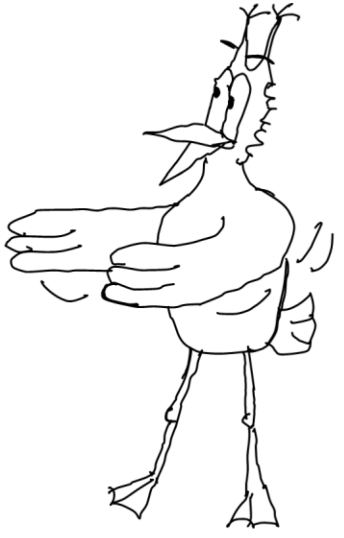


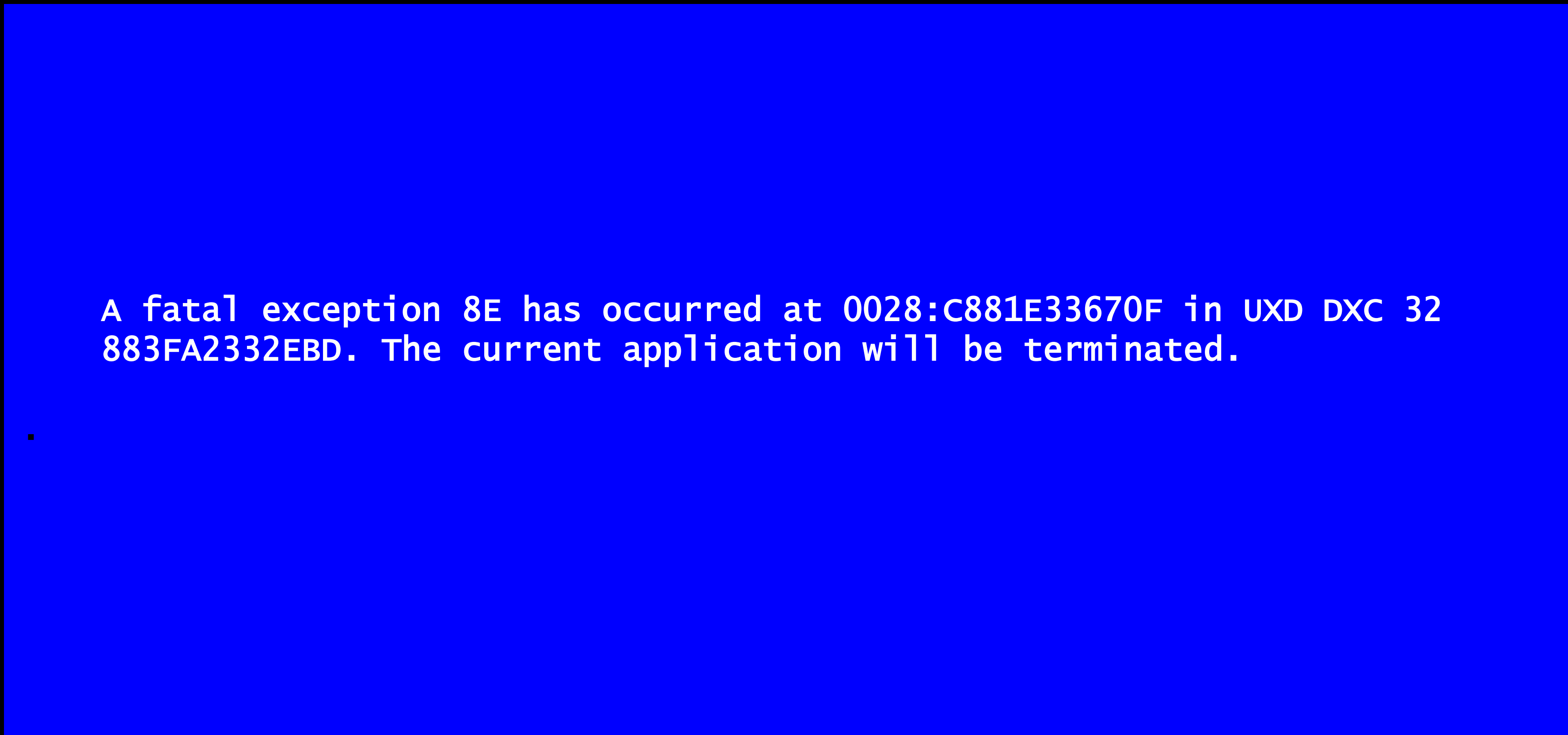
Wind energy production in MW of Eire in 2006. Source: Sustainable Energy - without the hot air by David JC MacKay (online)

ONE DAY IN THE LIFE OF ROBERT LONGIROD

One Day in the Life of Robert Longirod

- We are in May 2050, in the 3500W society
- Robert Longirod is telecom engineer at the swiss branch of Huawei Technologies





Home automation controller hung yesterday night. Hot water was not replenished overnight.

Robert is a philosoph and takes a cold shower.

Now is time for a good, hot, espresso. Robert imagines the smell of the first coffee of the day and smiles …

…but no coffee !

Robert re-programmed his end user preferences in the smart grid yesterday night and made a mistake !

Fortunately, the fridge works and there is some orange juice left.

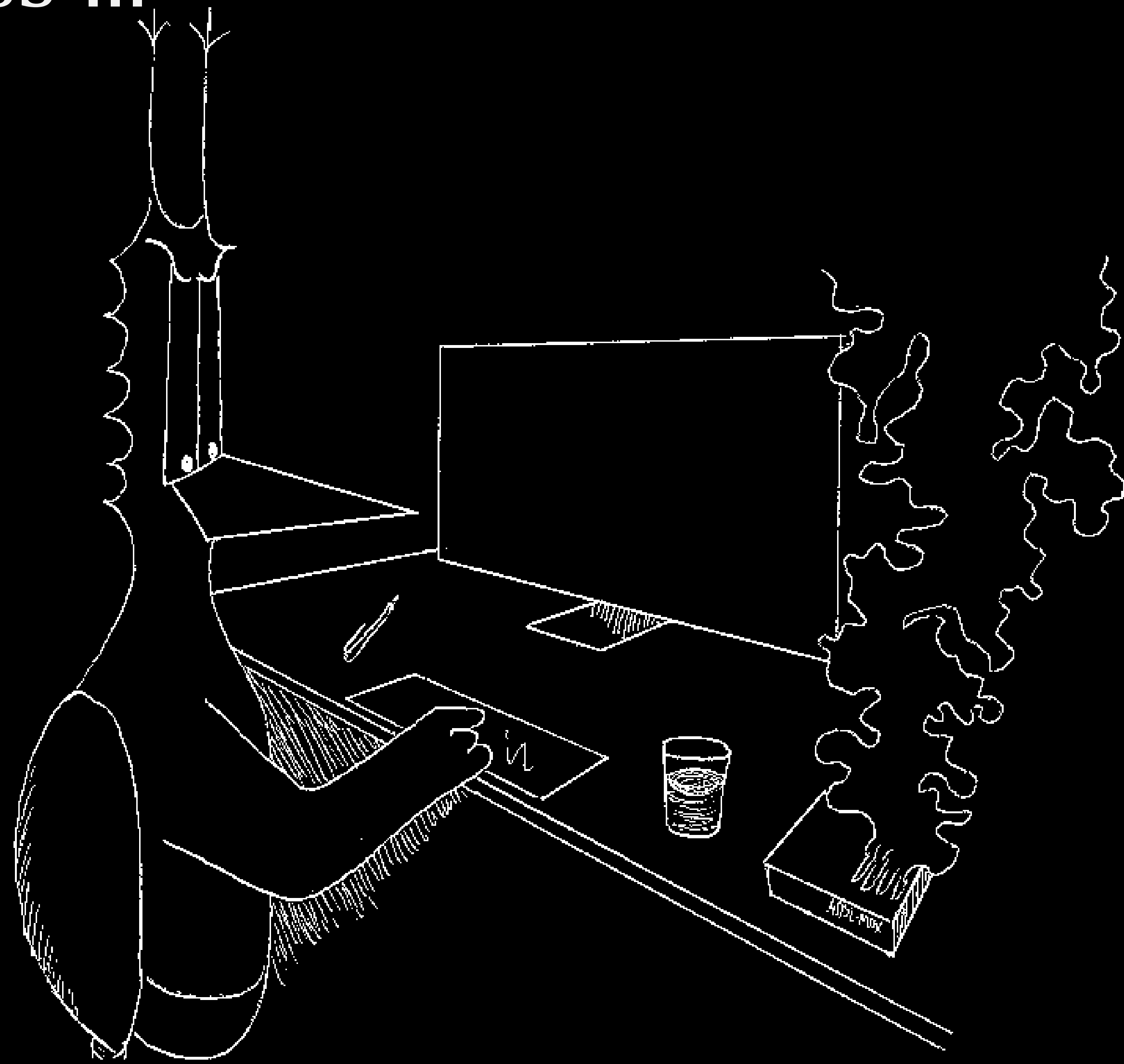
Robert now walks to his lounge and prepares to work. Today, Robert is telecommuting – this saves time and energy.

Strange, the lounge is dark – shutters are blocked closed … the home automation controller, of course !

Not a serious problem anyhow; the shutters can be opened manually.

Robert sits at his table and opens his desktop ...

The femtocell has burnt, no internet access …



Robert is a bit worried. There is an important meeting at 10:00 scheduled with two co-workers.

« If I am not at that meeting, it is George who will get the work. I must be there »

Robert decides to do something exceptional: drive to work !

In the garage ...

The e-car is not charged.

The batteries were used to power the grid. Normal, Robert did not plan to go anywhere today…

Robert cycles to work

While pedalling back home in the evening, he hopes that the washing machine did its job…

Intelligent Demand Management must Be Simple, Adaptive and Distributed

- Global, optimal schedules
  - are hard,
  - error prone
  - and do not account for last minute changes

- More realistic is
  - elastic demand,
  - with best effort service with statistical guarantees.

  - [Keshav and Rosenberg 2010]

Possible Directions for Distributed Control

Network

- Signals marginal price to users
- Whether a true price or a congestion signal is an issue

Users

- Delay / reduce demand
  - Defer heating / cooling /battery loading
  - Substitute local source
  - Substitute battery

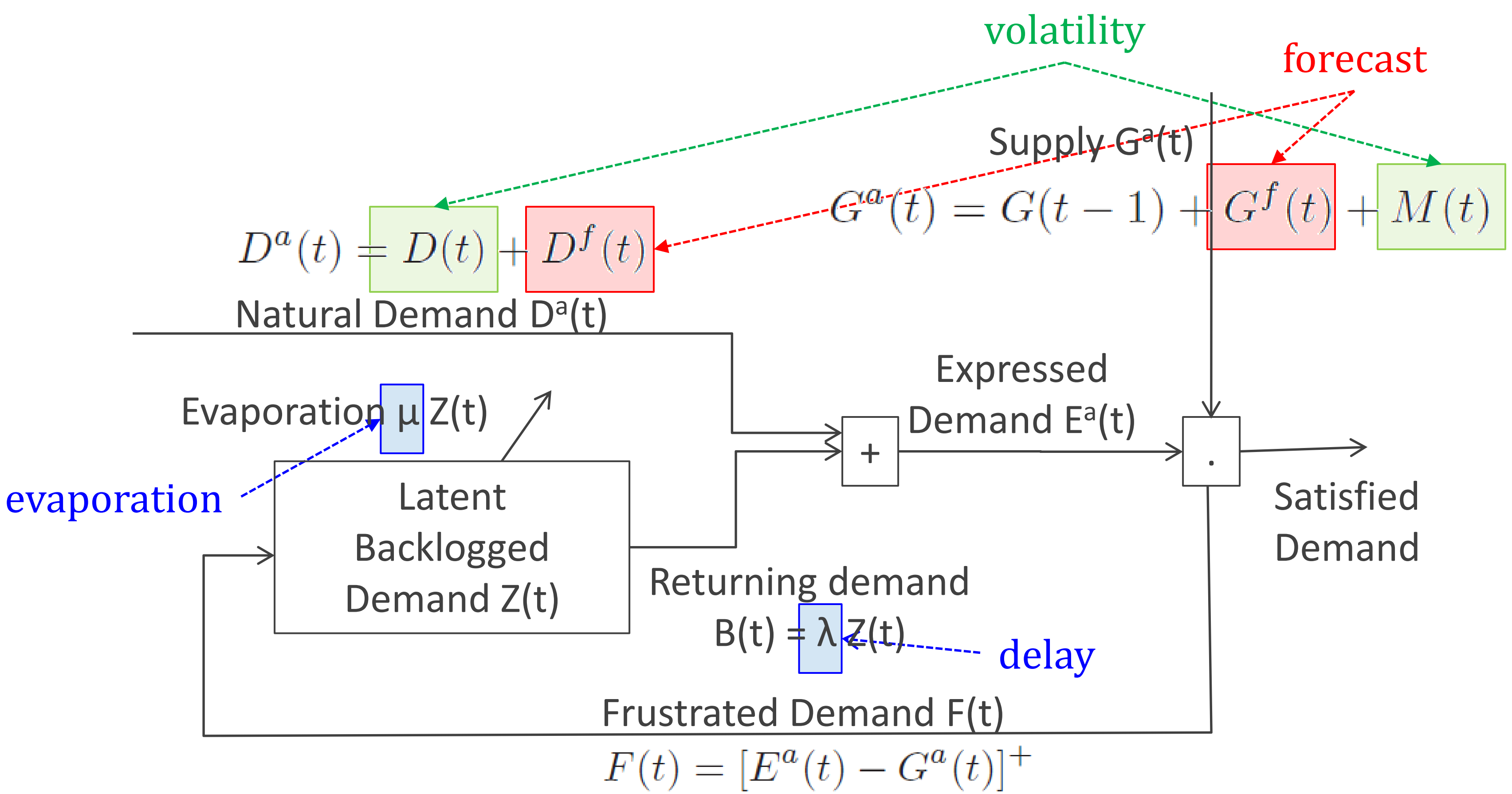
MODELLING APPROACH

A Preliminary Issue is Stability

- We want first to study if elastic demand / adaptation is feasible
- Assume supply is random and load is elastic
  - Users act a distributed buffer
  - Hot water tanks, batteries
- We leave out (for now) the details of signals and algorithms
- A very coarse, but fundamental criterion: is there a control mechanism that can stabilize demand
- Instability can be generated by
  - Delays in demand
  - Increase in demand due to delay

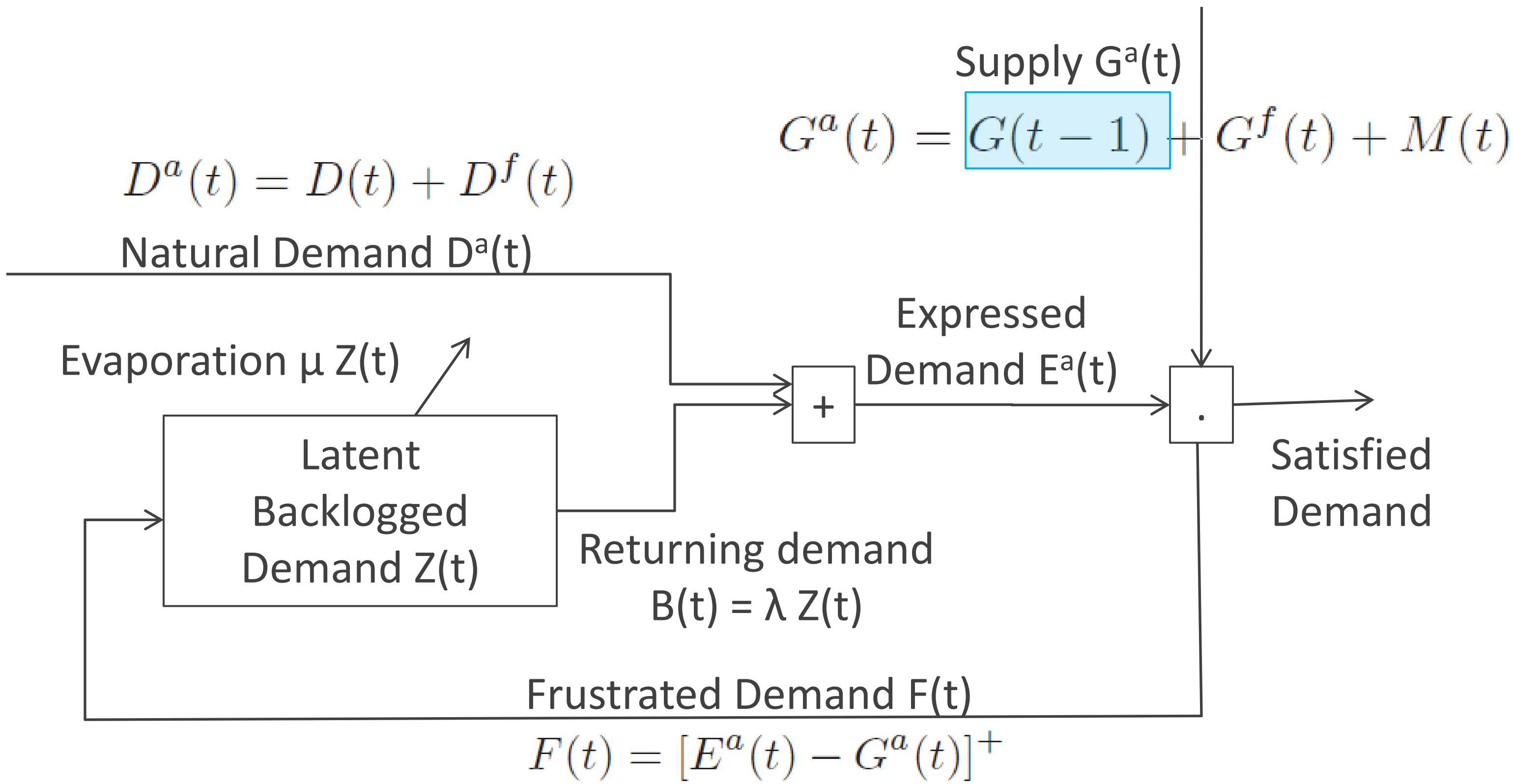
A Demand / Supply Model

- Inspired by [Meyn et al 2010]



The Control Problem

- Control variable: G(t-1), production bought one second ago in real time market
- Controller sees only supply $G^a(t)$ and expressed demand $E^a(t)$
- Our (initial) problem: keep Z(t) stable
- Assume ramp-up constraint only $G(t)-G(t-1) \leq \zeta$



Threshold Based Policies

$$G^f(t) = D^f(t) + r_0$$

Forecast supply is adjusted to forecast demand

$$R(t) = G^a(t) - E^a(t) + r_0$$

R(t) := reserve = excess of demand over supply

Threshold policy:

if R(t) < r* increase supply as much as possible (considering ramp up constraint)

else set R(t)=r*

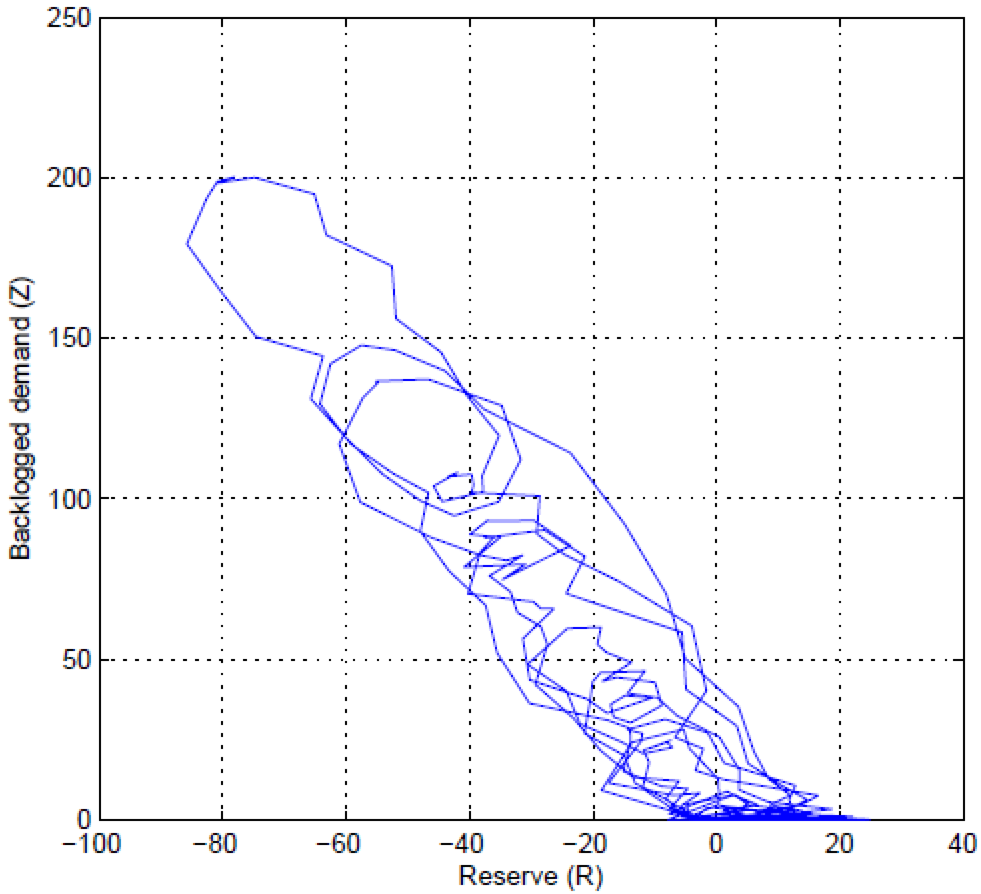
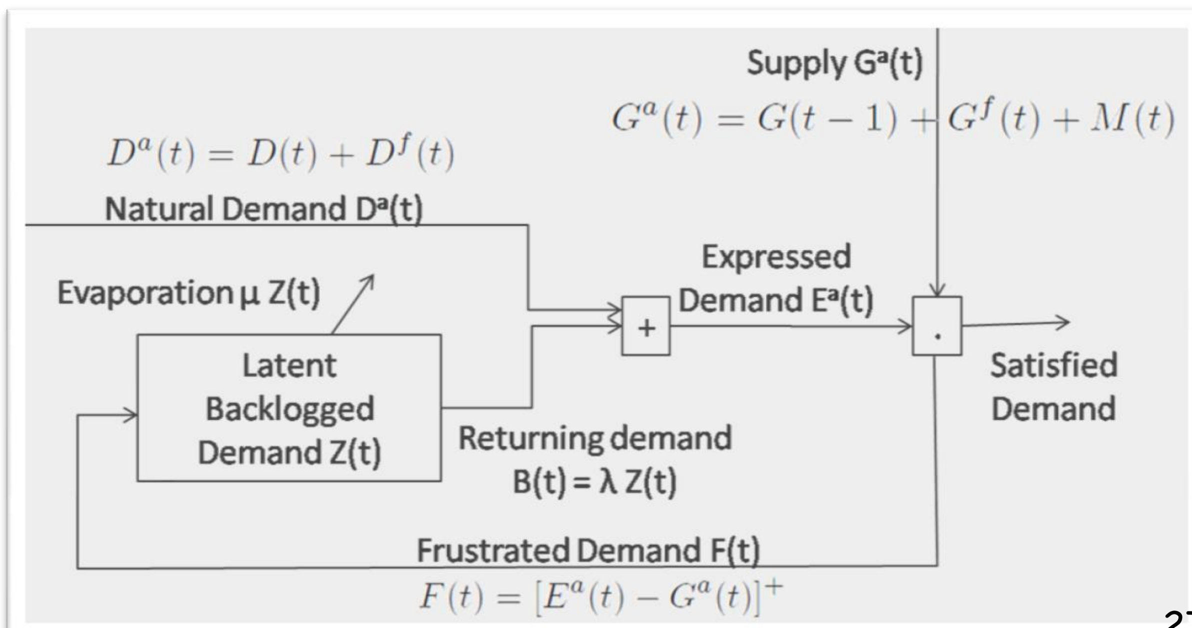


Figure 2. 500 iterations of the Markov process (13)-(14) for $\zeta = 1, r^* = 10, \sigma = 5, \lambda = 0.3, \mu = 0.1$

Findings

- If evaporation μ is positive, the system is stable (ergodic, positive recurrent Markov chain) for any threshold r*
- Delay does not play a role in stability
- Nor do ramp-up constraint and size of reserves
- If evaporation is negative, the system is unstable for any threshold r*

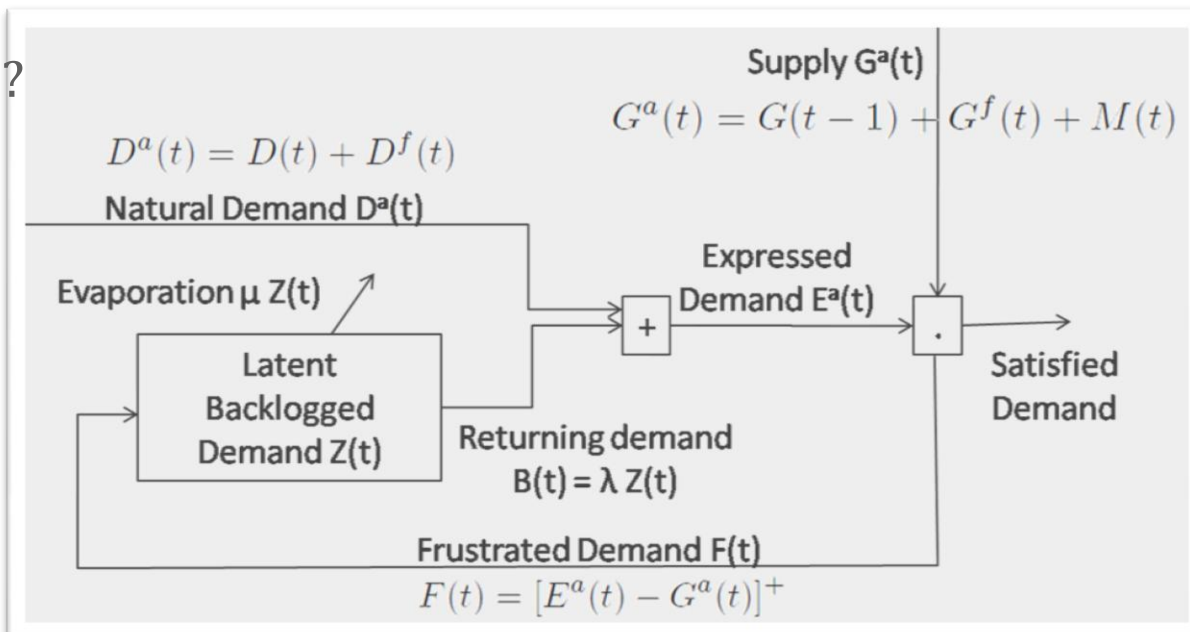


The Role of Negative Evaporation

- Negative Evaporation means
  - The simple fact of delaying a demand makes the *returning demand* larger than the original one.

    (do not confuse with the sum of returning demand + current demand, which is always larger than current demand)

  - Could that happen ?



Evaporation: Heating Appliances

- Assume the model [MacKay 2009]

heat provided to building $$d(t)\epsilon = \boxed{K}(T(t) - \theta(t)) + \boxed{C}(T(t) - T(t-1))$$

leakiness outside inertia

then delayed heating is less heating (this is what makes Voltalis be accepted by French households)

- Pure thermal load = positive evaporation
- This is true for heat provided, is not necessarily true for energy consumed
  - Depends whether coefficient of performance e is constant or not; true for resistance based heating
  - Delayed heating with air heat pump with cold air may have negative evaporation (bad coefficient of performance when air is cold)

Conclusions

- A first model of adaptive appliances with volatile demand and supply

- Suggests that negative evaporation makes system unstable,
  - thus detailed analysis is required to avoid it

- Model can be used to quantify more detailed quantities
  - E.g. amount of backlog