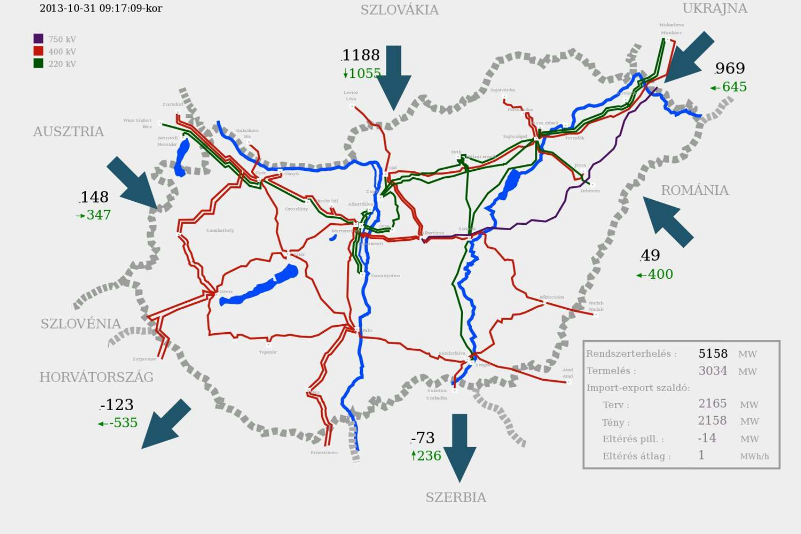
Energy flow control in Hungary and data sparsity in quantum systems

Örs Legeza

Wigner Research Centre for Physics, Budapest

Wigner-111, Budapest, 12.11.2013.

History and present challenges



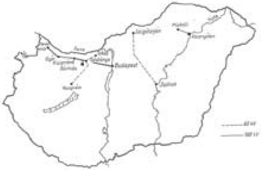
Topics to be covered

1. History of electricity in Hungary
2. OVIT the former unit of Mavir
3. Avir: research aims
4. Developments within 1953-78
5. Developments of system control
6. Bigdata
7. Data compression

History of electricity in Hungary

- 1878 arc-lamps in Ganz és Társa Vasöntô és Gépgyár
- 1884 current generators at Temesvár
- in 1920 most of the energy in Budapest was given by the Kelenföldi Erömű (138 MW)
- 1935 all the cities (56), and 30 percents of the villages (1020) had electricity

Development of the transmission network



1949 előtt

1979

1949

1989

OVIT the former unit of Mavir

- The National Electric-power Distributor (Országos Villamos Teherelosztó, OVT) was founded in 1949
- Dispatchers took notes on blackboards and communicated by telephone networks
- in 1949 it controlled 6 power plants and 11 sub-stations
- Major aims were:
  - measure power demand on daily, weekly and monthly basis
  - in case of power-failure the calculation of power-loss
- The first schedule for power plants connected to the strong-current network was issued in 1949

Avir: research aims

- Major aim of the network developments was to organize the operating and planned power units and major industrial costumers to a controlled network.
- Later power plants with smaller capacities were also included into the network
- In 1951 the OVT headquarter was founded but still remained part of Hungarian Electric Company (MVM).

Energy flow control is a major research field

- The first theoretical research units were founded in 1938
- Later others followed among many others:

  • the OVRAM (Országos Villamos Relévédelmi, Automatika és Mérésszolgálat) and

  • the Villamosipari Központi Kutató Laboratórium (VKKL)

New challenges within 1953-78

- New challenges to be solved: the development of the 400 kV networks in the vicinity of Paks Atomic Reactor
- OVT had to fulfill demands related to the sudden fluctuations in energy consumptions in the morning and evenings
- Need for local control units: Local Dispatcher Services (Körzeti Diszpécser Szolgálatok (KDSZ-ek).
- National network was connected with networks of the surrounding countries: more intense energy flow through the non-homogeneous networks (compatibility problems related to the differences between the SZU EVER and CDU systems)
- In the 1960s digital technology started to gain more attention

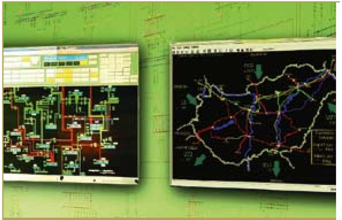
Developments of system control

- Major 750 kV network developments and several new nodes with multi-line connections
- Tasks of transmission control could not be solved by humans: need for remote data collection, fast data transfer and on-line data analysis
- The system operation related tasks were controlled by a Hitachi 2xHIDIC-80 computer system
- In the 1980's a computer network dedicated to system control related tasks were developed (OVINET)
- The Hitachi central unit was further developed reaching its peak in 1988: HIDIC–80 three-parallel unit.
- This system was operated until 2000 for more than 21 years and controlled more than 100 power units and several thousand sub-stations.

Recent system control

- Nowadays the EMS SPECTRUM-SCADA control system is responsible for most of the tasks related to energy flow control within the country.

Az OVT vezénylője a 90-es években



Az EMS/SCADA rendszer logikai konfigurációja

- MAVIR started to become an independent unit since 2001 taking care of more and more complex tasks. Since 2006 it also controls the energy flow across the border.
- Opening of the market in the energy sector has raised even further tasks to be solved.

New challenges and problems

- Optimizing network topologies
- Optimizing schedule based on power demand and the market
- Redundant functionality units
- Off-site redundancy
- Remote control
- Information Technology (IT)-Security: dedicated networks, secure communication but also public data release
- Energy flow control units are key issues for National Security

Big-Data, correlations and graphs

- Nowadays, measurements are made in milliseconds, and these data are processed locally by intelligent metering-units which transfer relevant data to the central unit for further data analysis.
- Correlation calculations also generate huge data (several TeraBs, even PetaBs)
- Need new technology for data management: Big Data Science
- Similar demands in quantum physics: simulation of quantum systems on classical computers

Efficient simulation of quantum systems on classical computers?

- R. Feyman (1985): simulating quantum systems on classical computers takes an amount of time that scales exponentially with size of system, while quantum simulations can scale in polynomial time with system size.

- Tensor network states as low-rank approximations of high-dimensional tensor spaces $\rightarrow$ efficient simulations on classical computers with polynomial costs

- Major aim: no need to build expensive laboratories and experimental environments to design new materials and system just simulate them on computers

- In certain cases we can already reproduce and simulate experimental results

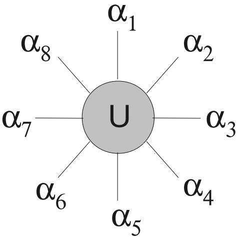
Major aim:

For example using a spin-orbit basis (d=4):

$$|\alpha_i\rangle \equiv |0\rangle, |\downarrow\rangle, |\uparrow\rangle |\downarrow\uparrow\rangle$$

Wavefunction in full tensor form:

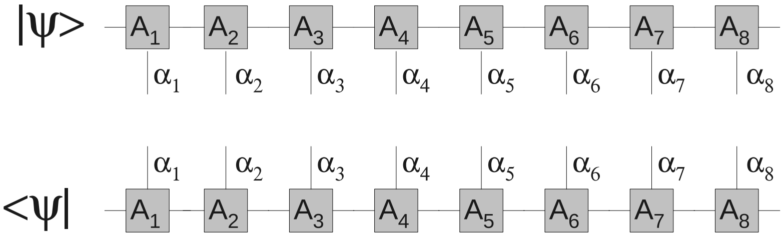
$$|\Psi\rangle = \sum_{\alpha_1,\cdots,\alpha_N} U_{\alpha_1,\cdots,\alpha_N} |\alpha_1, \cdots, \alpha_N\rangle$$



Tensor product approximations:

- Matrix Product State (MPS) representation:

$$|\Psi\rangle = \sum_{\alpha_1,\alpha_2,\ldots,\alpha_N}^{d} \mathrm{Tr}\left(\mathrm{A}^{1}_{\alpha_1}\mathrm{A}^{2}_{\alpha_2}\cdots\mathrm{A}^{\mathrm{N}}_{\alpha_\mathrm{N}}\right)|\alpha_1\rangle|\alpha_2\rangle\cdots|\alpha_\mathrm{N}\rangle$$



$$A_i[m,m]_{d_i}$$

- We can call this as a network.
- The Density Matrix Renormalization Group (DMRG) is a special algorithm that provides the optimized set of A_i matrices.

Tensor product approximation

Approximation of a single tensor, or even an ensemble of tensors $\mathbf{u}_y$, $y = 1, \ldots, m$, in tensor product spaces,

$$|\mathbf{u}_y\rangle = \sum_{x_1=1}^{n_1} \cdots \sum_{x_d=1}^{n_d} U(x_1, \ldots, x_d, y)\, |x_1\rangle \otimes \cdots \otimes |x_d\rangle \in \bigotimes_{i=1}^{d} V_i := \bigotimes_{i=1}^{d} \mathbf{C}^{n_i}$$

where $span\{|x_i\rangle : x_i = 1, \ldots, n - i\} = V_i = \mathbf{C}^{n_i}$. If there is no ambiguity with respect to the basis vectors $|x_i\rangle$, $x_i = 1, \ldots, n_i$, we can identify $\big(|\mathbf{u}_y\rangle\big)_{y=1}^{m}$, with the discrete function

$$\Big(\ (x_1, \ldots, x_d) \mapsto U(x_1, \ldots, x_d, y)\Big)$$

i.e. $x_i = 1, \ldots, n_i$, $y = 1, \ldots, m$.

DMRG, MPS, TT

A special representation of U if we introduce the matrices $\mathbf{U}_p(x_p) \in \mathbb{C}^{r_{p-1} \times r_p}$ by

$$\left(\mathbf{U}_p(x_p)\right)_{k_{p-1},k_p} = U_p(k_{p-1}, x_p, k_p) \ , \ 1 < p < d \ .$$

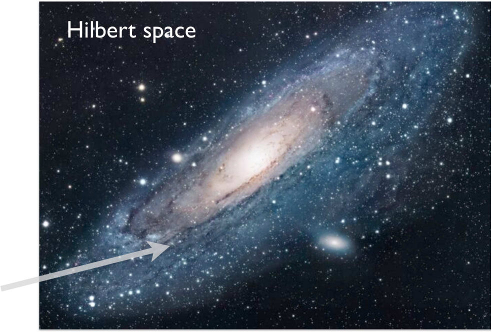
Then we can represent the tensor by matrix products

$$U(x_1, \ldots, x_d) = \mathbf{U}_1(x_1) \cdots \mathbf{U}_p(x_p) \cdots \mathbf{U}_d(x_d) \ .$$

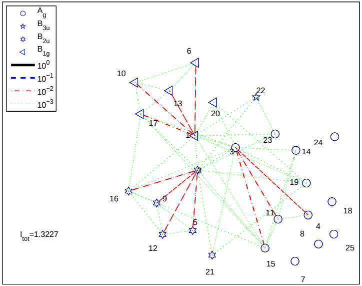
Density matrix renormalization group (DMRG) method (White, 1992)
Matrix product state (MPS) (Östlund and Rommer, 1996; F. Verstraete and Cirac, 2004)
Tensor Train (TT) (Oseledets 2009; Hackbush 2009)

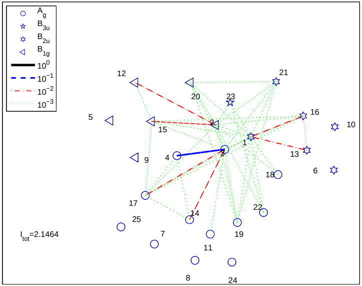
Complexity of finding the required state

- contains ground states of short-ranged Hamiltonians
- merit of TNS: parametrize this set efficiently!



Entanglement → Multiply connected networks





LiF at r=3.05 LiF at r=13.7

Rissler, White, Noack, ECP (2006)

Murg, Verstraete, Schneider, Nagy, Legeza (2013)

- DMRG → Matrix product states, i.e. optimization along one-spatial dimension
- Need for an algorithm that reflects the entanglement topology of the problem → Tensor Network State (TNS) methods
- Use tensors $[A_i]^k_{\alpha_1 \dots \alpha_z}$ where z is the coordination number

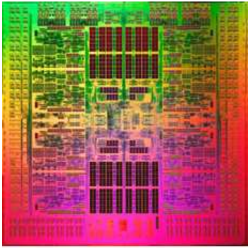
Fujitsu: K computer 10.51 petaflops

- DDMRG simulations: ACM Gordon Bell Prize in 2012
- Number of processors: 88,128
- Total Memory capacity: More than 1 petabyte

Fujitsu: K computer 10.51 petaflops

- The 6-dimensional mesh/torus topology in the K computer provides many communication routes between neighboring CPUs.
- Execution of data communications between CPUs via the shortest route and over the shortest period of time
- CPU: Fujitsu SPARC64 VIIIfx processors:
  2.2 gigaflops per watt
- Water cooling system for its major components

"6-dimensional mesh/torus" topology (model)



SPARC64™ VIIIfx