

How to Liberate the World from Oil: Intelligent Systems for Cars, Trucks and Electricity Generation Without Fossil Fuel

Dr. Paul J. Werbos

personal, **not official**, views

Sources: IEEE-USA, IEEE, NSF, US Senate, UN
State of the Future; 1979-89: EIA/DOE lead analyst
for long-term energy futures. Updated 9/22/9.

Outline

- **Why** we need to liberate the world from fossil oil as fast as we can
- **How** we can: general strategy
 - New legislation to move as fast as we can/should
 - Intelligent systems to use and maximize alternative liquid fuels
 - Intelligent systems to better use and make electricity
- The need for new **intelligent systems** – using neural nets and adaptive dynamic programming (ADP) to get adaptive optimal nonlinear control, taking advantage of pattern recognition for better prediction and decision
 - Recent breakthroughs: brains, ADP and prediction

www.werbos.com: click on energy or on neural networks

3. SCENARIOS OF THE PERSIAN ARABIAN GULF

3.2 Scenarios of Security and Peace

Escalating the importance of the region for western civilization



The use of oil as a weapon in confrontation between Western and Muslim societies is the main concern of the strategic decision makers in the west. This use will make the military power useless without fuel. It will remain pile of metal scrap.

Why Liberation From Oil is of Highest Urgent Importance to Humanity

- In 15-25 years, many fear that we will all become hungry rats fighting for the last piece of cheese (oil). This, not CO₂, is the **greatest near-term threat** to the survival of humans.
- **Oil money** now funds corruption and reactionary teaching all over the earth, reversing human progress. Without more progress, the trends of the earth are unstable and dangerous. (Paying to control oil in the ground is the underlying problem; refining, distribution and alternate sources are fine, offering a more sustainable future for oil companies.)
- Last year, the **cost of oil** was crippling to car drivers and to the world economy. We must act fast to limit the damage as oil prices rise again. Market foresight, not speculation, could raise the US oil bill back to about \$1 trillion/year unless we act now to change expectations.
- Because it will take 15-25 years to be totally free from oil, even if we hurry, it is **essential to act now** before it becomes too late.
- Liberation from oil is a **new path to reducing CO₂**, much more effective and affordable than the old ways.

Grand Strategy for Liberation From Oil



Maximize Fuel-Flexible Plug-in Hybrid Cars



Open door to US natural gas (e.g. to trucks) while it lasts

R&D for more efficient use of diverse fuels

R&D for batteries for affordable electric cars



Minimize cost and then maximize supply of renewable electricity

Maximize supply of Alternate liquid fuels
– Not oil
– Incentives, standards and R&D

GEM Flexibly Fuel Vehicles (FFV) One Tank To Hold Them All

G: Gasoline

E: Ethanol

M: Methanol



With an FFV, you choose each day which to buy
At \$100-200/car, a more open competition, level playing field,
better unleash the power of the free market
GEM flexibility \Rightarrow use of any corrosive fuel, adaptive engine
control

Plug-in Hybrids (PHEV) : A Large-Scale Opportunity Here and Now

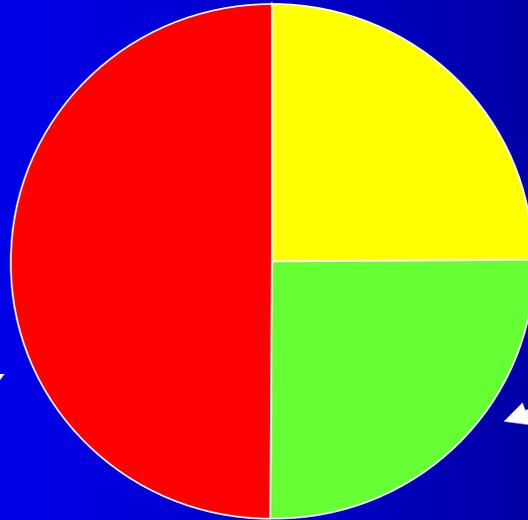
- Hybrids cut liquid fuel use 50% already. Plug-ins cut **50% of that**.
 - “Researchers have shown .. (PHEV) offering.. electric range of 32 km will yield... 50% reduction..” (IEEE Spectrum, July/05). Shown in working Prius.



- Battery **breakthroughs in China**: from 10/07, 10kwh batteries (larger than) cost **\$2,000**. www.thunder-sky.com. Thus an extra \$2,000 per car can cut gas dependence in half.
- **Gives economic security in case of sudden gasoline cutoff.**
- **Does not strain grid – actually strengthens it, if done right**

How To Zero Out Gasoline Dependency: Best Near-Term Hope for 100% Renewable Zero- Net-CO2 cars & **Total Security** for Car Fuel

Highest mpg
Hybrids Cut
Gas per Mile
By 50%



With **GEM fuel-flexible** cars,
biofuels might supply $\frac{1}{4}$
of present liquid fuel
demand trends

Plug-in Hybrids
with 10kwh batteries
get half their energy
from electricity

GEM fuel-flexible plug-ins offer a 100% solution based on near-term
technology! www.ieeeusa.org/policy/positions/PHEV0607.pdf

IEEE Computational Intelligence Society – Alternate Energy Task Force

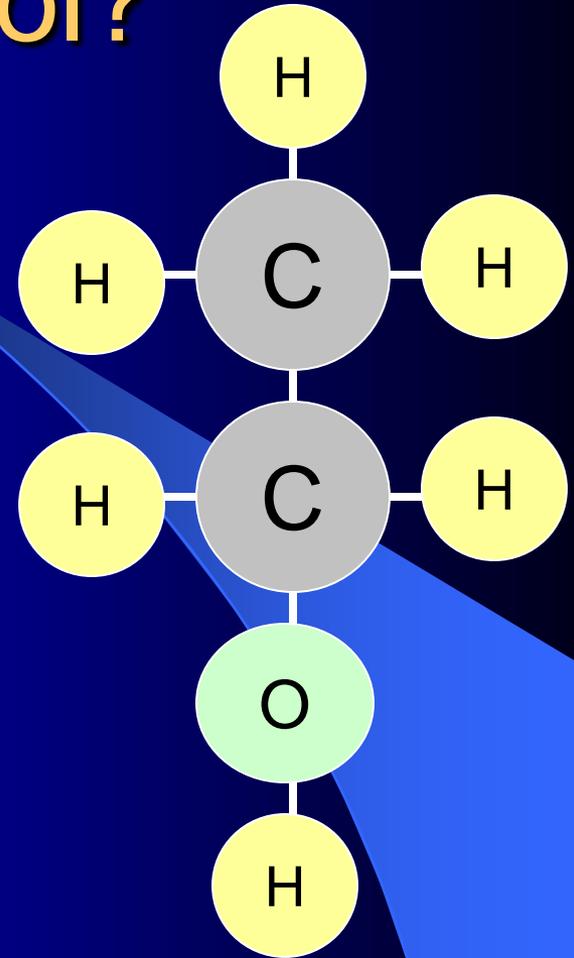
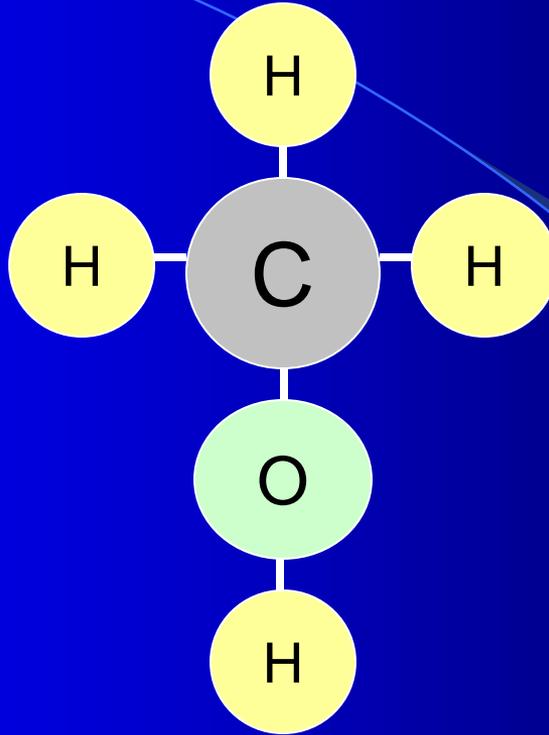
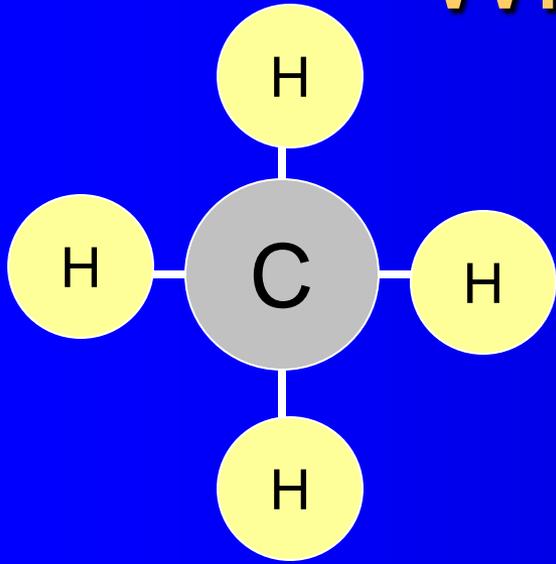
<http://iee-cis.org/isa/alternative/>

- Rajashakeera, Rolls-Royce
(former Delphi hybrid leader)
 - Prokhorov, Toyota
 - Anya Getman, Caterpillar
 - Marko, Bosch
 - Feldkamp, Ford
 - Javaherian, GM
 - Bonissone, GE
 - Zimmerman, Siemens
 - Fei-Yue Wang, Chinese Academy of Science
 - Chair: Werbos
 - Estevez
 - Fukuda
 - Sarangapani
 - Venayagamoorthy
 - Liu
- Research for Honda, Caterpillar, ABB, Others
- Some serious reshuffling since auto bankruptcies, endangering clean air

New Legislation Is Also Essential, To Move As Fast as We Can & Should:

- Thanks to Senate Legislative Counsel: bill & explanations posted at last paragraph of www.werbos.com/energy.htm. All 4 together to escape “who goes first”:
- For vehicles:
 - Extend tax incentives for **all** fuel-flexible and hybrid vehicles (including plug-ins and even fuel cells) until most cars sold are “futuristic cars.” Need the extension **now** to allow new investments aimed at future. (Pryor/Inhofe.)
 - Require GEM flexibility in liquid fuel systems (open fuel standard, Brownback).
- For refueling stations (recharging or gas stations):
 - Extend tax incentives, include retrofit and public access electric recharging.
- For actual fuel use and production:
 - Modification of Waxman/Markey “Low Carbon Fuel Standards,” with penalty for oil shale removed, credit for natural gas and electricity required, and faster encouragement of new technology/fuel/combinations
 - Support prices for alternative liquid and gaseous fuels
- Aggressive new R&D:
 - \$60 million for **well-focused** new R&D living up to unmet opportunities here, through ARPA-E/NSF partnerships open to all universities, small business, etc.

What IS Methanol?



Methane

Natural Gas
Scarce as Oil
Needs Special
Tank

Methanol

Good H Carrier
Can Be Bioliquid
Or From Coal, Gas

Ethanol

e.g From Corn
Drinkable

Nonfood biofuels could supply half our fuel needs using old technology – if we stop demanding purity in our ethanol/alcohol!



We need to give this guy permission to compete with Saudi Arabia and Iran for the car fuel market! He doesn't need a subsidy – only more freedom and an open door! Just give him a chance, and within 15 years...

(Also, try a google on “forest industry” methanol.)

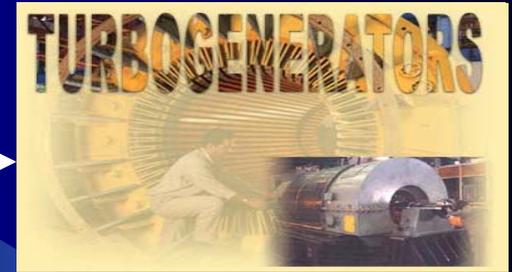
Fuel flexibility can be brought online very quickly, much faster than hybrids merely doubling every year!



All major manufacturers which sell in US have sold such cars in Brazil!!

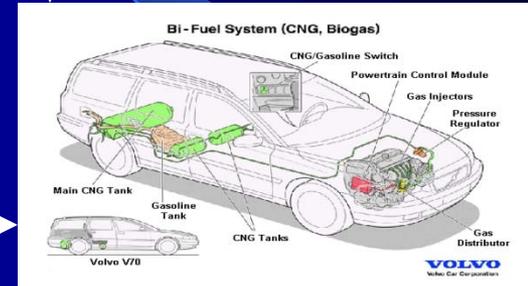
Limits of 3 Paths from Natural Gas to Cars

US
gas



Not enough

Liquefy, transport
and import (LNG)



\$6200 more per car

Make methanol, transport
and import (\$160/ton or new
high efficiency GTL)



**GEM-flexible car: <\$200
more per car**

BUT US gas supply has grown a lot lately, deserves level playing field, and can help a lot with trucks in next few difficult decades!!

Remote
or nonUS
gas

May 2009: Big New Fuel Opportunities 1

- **Cheap methanol now.** In 2012, we expect 11 billion gallons per year of excess methanol supply at \$0.60/gallon from remote natural gas (RNG). Lots more RNG available. New direct catalysis technology lets us get twice the methanol per natural gas.
- **Better coal to liquids.** CoalStar is one step away from 4 barrels per ton of coal, twice what China buys today, **no gasification**, no emissions. After \$10 million pilot plant, cost expected to start at \$50 per barrel, decrease from there.

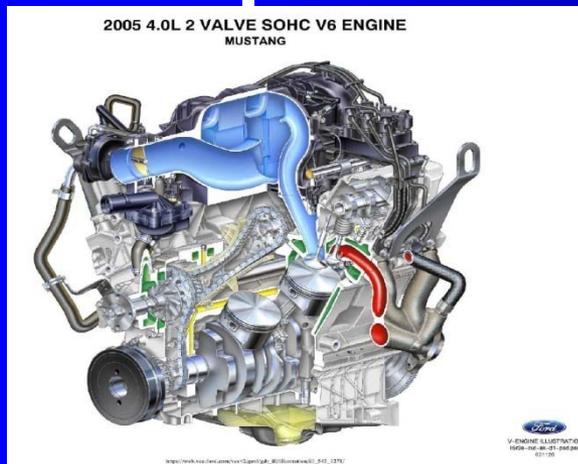
May 2009: Big New Fuel Opportunities 2

- **Fuel From Flue (smokestack gas)**. Many US companies have technology, but big new opportunities abound. For example, Aurora says CO₂ streams from old coal or steel plants produce crude oil at \$60/barrel. This cleans up CO₂ and creates fuel at the same time. No more need for special (IGCC) coal plants to clean up CO₂!
- **Thermal/chemical processing of grasses and wood waste**, to mixed alcohols. May even double fuel per ton of biomass, versus the usual cellulose.
- DOE/EPA estimate that nonfood biomass can sustainably supply **half the present US car fuel demand**.

How to Capture the Opportunities

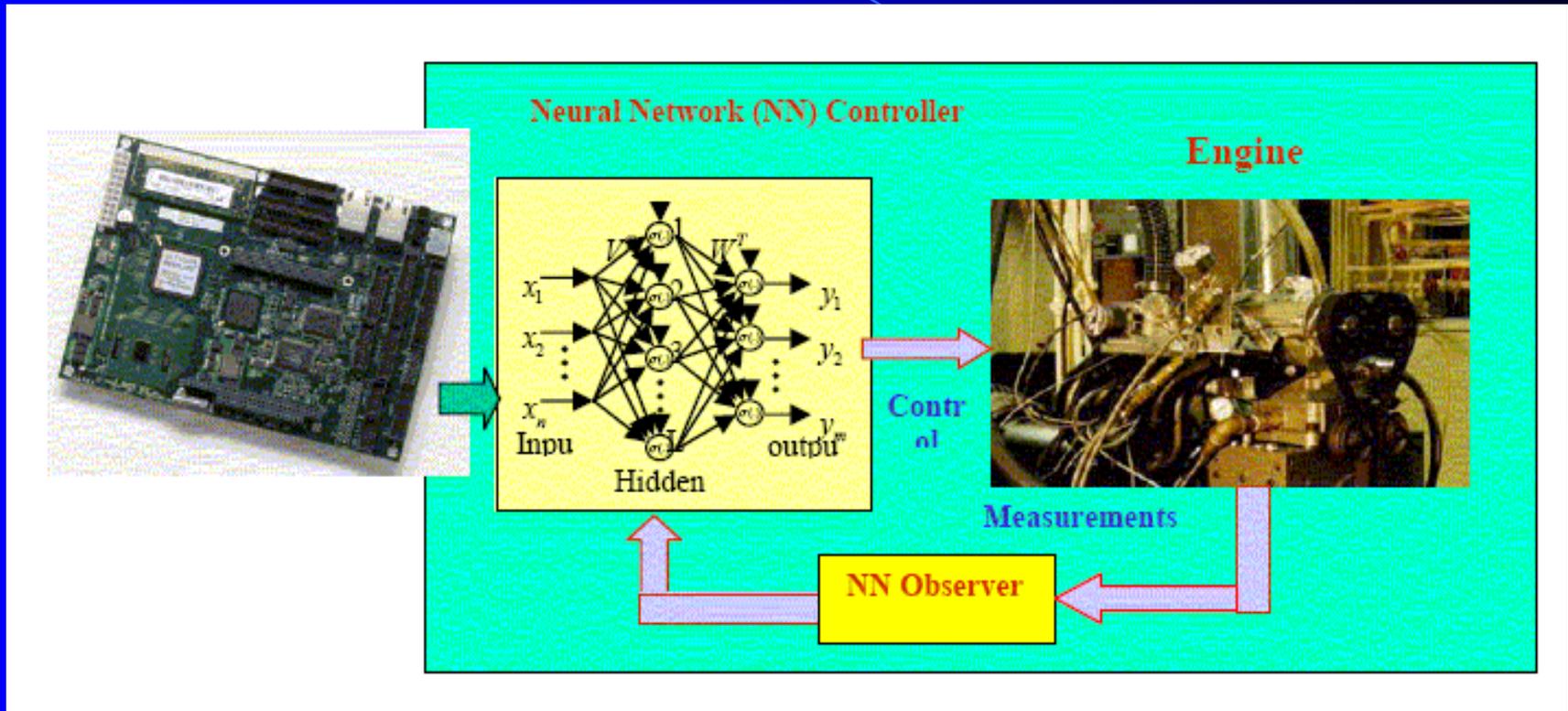
- Engineering level: **use new neural ADP technology** to get optimal performance (nonlinear adaptive optimal control):
 - Minimize fuel use and pollution adaptively across a wide mix of fuels “in the triangle of Gasoline-Ethanol-Methanol”. (e.g. build on Ford Marko diagnostics and Sarangapani.)
 - Optimal adaptive management and stabilization of tricky, nonlinear bioreactors (simulations by Ford and Wunsch)
 - Pattern recognition and adaptation in processing of wood products and other biomass (Sweden wood generators)
- Policy level needs:
 - LAW for fuel flexibility; China needs US action S835
 - Price supports to encourage new fuels (\$75 for coal-based, \$100 for renewable or flue, \$120 for true life-cycle carbon)
 - Whatever we gave to carbon capture and sequestration, stop, and give instead to carbon capture and re-use.

Ford 1998: “All Ford Cars Will Have TLRNs by 2001, for on-board Diagnostics”



- How can one neural network predict and diagnose all Ford engines, without retraining, even as they change over time? TLRN: adaptive prediction even without learning! ICNN05: “A neural network which can predict anything.”
- IJCNN07, Prokhorov: TLRN prediction and control can improve mpg of Prius hybrid by 15% “at zero cost”!

ADP Controller Cuts NOx emissions from Diesel Engines by 98%



J. Sarangapani UMR NSF grant

- IJCNN07: JS shows mpg up 7% in ordinary car engines with ADP
- Prokhorov shows mpg up 15% in Prius hybrid with Neural MPC

Near-term Breakthrough Possibilities For Fuel To Electricity in Cars

- Goal is to replace the 30% efficient small gasoline engine inside the world's best hybrids, to cut their fuel use in half again, while retaining fuel flexibility
- 40-55% efficient Stirling engine. Requires new ideas and special skills of Lennart Johansson, inventor of a working Stirling engine back when many tried and few succeeded.
- JTEC (www.johnsonrd.com)
- Automotive solid oxide fuel cell? (Rajasakera)

China, US, Japan and Korea: Who Will Win the Race towards Plug-In Cars?

Dr. Paul J. Werbos

-- personal, **not official**, views
IEEE-USA, IEEE, NSF,
UN State of the Future
1979-89: EIA/DOE lead analyst
for long-term energy futures

www.werbos.com/energy.htm



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The view from Morgan-Stanley

March 11, 2008

- “We see lithium-ion PHEVs today as akin to MP3 players in 1998. They are likely to revolutionize the automobile as we know it, but it still unclear who will develop the equivalent of the iPod”
- Projected battery costs: \$4,025 for 7kwh (20 miles all-electric) , \$5,585 for 14kwh (GM Volt)
- www.vvcars.com/pdf/PHEV_MorganStanley.pdf

World's First Mass Market PHEV

2nd half of 2008: BYD Motors F6DM



- 20 kWh battery, 65 miles all-electric driving range
- Made in Shenzhen, China
- Follow-on in 2009: F3DM, 100 miles all-electric
- www.byd.com

Other contenders

- GM Volt, 14kwh, 40 miles: planned for late 2010, using A123 or LG Chem advanced lithium battery. **Enough for 90% of US to get to work** in case of total gasoline embargo, if employer parking lots have recharge stations.
- Hyundai: US mass-market hybrid 2009, no comment on plug-in, deal with LG Chem and massive new Korean battery program www.eetimes.eu/power/196600822
- Toyota: 2010 PHEVs to fleet owners only, a test, using **proprietary** advanced lithium-ion battery and power electronics technology GM cannot buy. Plans to keep doubling hybrid output every year.
- Chery (China) says by 2010: half of its million cars per year will be hybrids, half of them on alternate liquid fuels. 40% will be for export.
- Dongfeng Electric Car Company, and Chang'An

What limits rate of deployment of hybrids & plug-ins? Cost, cost, cost...

- Hybrid Prius vs. regular Prius: cost penalty = **\$3000** (2006 data Car & Driver, Financial Times) about enough to pay off at \$3-4/gallon without interest
- About **\$2000** of the \$3000 is for small fast battery, currently nickel hydride less than 1kwh.
- **\$1,000-\$2,000 tax incentive** per car, for the first million hybrids from each manufacturer, essential to speed of development, becoming cheaper, **in US**
- **Outside the US**, higher gas price bigger market now, but subsidized gasoline prices in China cheaper than US

What would accelerate plug-ins most?



Dr. Abe, leads all of
Toyota hybrid, plug-in
& electric car
development

Me

Prof. Toshio Fukuda

- Toyota response December 4, 2008:
 - **Permanent** tax incentives (not just 4 years)
 - Promote **recharge posts everywhere** (cuts fuel use in half again, energy security, attracts consumer)
 - **Standards** for recharge posts – quicker recharge, compatibility, eventually V2G

Lithium Iron Phosphate Batteries: The One Proven Key to Breaking the Cost Barrier

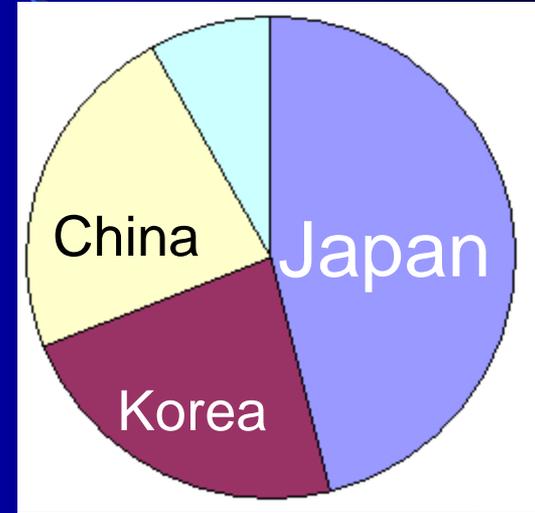


- Invented in 1997 by NSF grantee Prof. John Goodenough, U. Texas
- Winner of the Japan Prize
[www.japanprize.jp/e_2001\(17th\).htm](http://www.japanprize.jp/e_2001(17th).htm)
- Recent huge surge in production at:
 - A123, to manufacture in China
 - LG Chem
 - BYD (Shenzhen), claims to be world's #2 producer of rechargeable batteries
 - Thunder Sky (Shenzhen), safety add-on

How incentives/markets are changing the game: Better batteries are coming



Thunder Sky, China, 10kwh now \$2000
(Werbos in-depth visit June 2007)



World Li Battery Output

Toyota says it will go to Li batteries next year or so, that its new joint venture with Mitsubishi is far ahead of everyone else. But Korea's new thrust aims to beat Japan in rechargeable sales by 2012, by focusing on next generation technology.

New US-China Opportunity?

Some highlights from Shenzhen...

- Plan to get to **\$1000** for 14kwh battery is in place.
- Thunder Sky says **zero water runoff** in manufacturing. **Shenzhen** says electronics, clothing, batteries, leather industries about equal as sources of pollution overall. Recycling of batteries needed, but global PHEV use would maybe double the (limited, sustainable) issue we have already from lead-acid batteries. Safety > Toyota.
- Ready now: mass production in 2007 of amazing 150-mile electric motorcycles in China. High performance!
- Can **REPLACE** today's hybrid batteries: power surges are easier when the battery itself is bigger.
- For GM use, need: (1) intelligent 300-volt battery management system (computational intelligence can do it!); (2) neutral US-funded battery & system testing facility, credible to GM etc.



China Government Plan

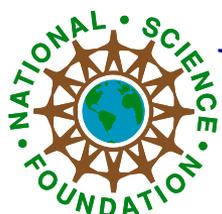
China Daily, posted in chinaview 10/27/7

- Wan Gang, new Minister of Science and Technology & “sea turtle”, strongly supports New Energy Vehicle Key Project of the National Hi-Tech R&D Program.
- Zhen Zijian, Deputy Director:



“(this is) the priority for China’s auto industry, which is expected to become the world’s largest in 10-15 years.”

- Ouyang Minggao (Tsinghua):”.. an innovative union of private companies, research bodies & universities.. along 3 paths – hybrid, clean fuel and electric vehicles.” Also google Caijing magazine.
- Chery says the A5 hybrid 4-door sedan will be \$1,400-\$2,900 higher than conventional version which starts at \$9,975.



Workshop on “Drug Discovery Approach to Breakthroughs in Batteries” Sept 8-9 at MIT

- | Focus: How could new crossdisciplinary research maximize the probability of breakthrough battery designs, suitable for new plug-in hybrid cars but costing only half as much or less as what is coming already?
- | Motivation: IEEE white paper argues that fuel-flexible plug-in cars offer our best near-term hope for independence from oil imports, but the high cost of batteries for new cars like the GM Volt is the main obstacle.
- | Sponsors: ECCS. Participation from DOE, DARPA, GM. Strong encouragement from OSTP. <http://web.mit.edu/dsadoway/www/nsfworkshopMain.htm>
- | Key findings:
 - » The “design space” is huge, and poorly explored due to cutbacks in US electrochemical engineering (other than fuel cells), and the slow speed of traditional Edisonian “shake and bake” methods.
 - » Systematic exploration, using computational approaches (quantum modeling, learning from data, stochastic search) as now used in the pharmaceutical industry show great promise. Sang-Tae Kim, former OCI Director, helped build new partnerships here.
 - » The uncertainties are great, but somewhere between 2X and 10X improvements are likely to be possible, if we follow up on this opportunity. No one else is doing it yet in the US.
 - » A new EFRI topic in this area would have huge workforce benefits for the US in this key area even in the worst case where GM imports batteries from China, whose industry is now well ahead of the US industry in this area.
 - » In addition to battery design, new lifetime analysis, catastrophic safety analysis and open-source models for battery management systems are all badly needed.

3 Linked Big Threats Already Cost us \$

-- We need you to help solve ALL 3!



CAR FUEL SECURITY: Can US economy still work and feed us all if oil is cut off or unaffordable? Is there hope we can pay less for fuel?



DAYTIME ELECTRICITY: Will we have shutdowns if imports of natural gas to US or EU or Latin allies is cut off or unaffordable?



24-HOUR ELECTRICITY: Can we make large scale renewable electricity (solar) cheap enough, soon enough worldwide – before every terrorist cell in the world has material for many bombs & CO₂ ⇒ far worse hurricanes & maybe more snowstorms in Europe, and hunger... ?

Three “Team A” Technologies for Renewable Electricity

- We know that all three CAN WORK and CAN provide all the US and China energy needs cleanly
- Most near-term: **wind farms**. 1/3 of US new nameplate capacity last year. But effective capacity is 1/3 of that, and **we throw away 2/3 of that** due to lack of storage in the grid and lack of control intelligent enough to make full use of the storage. We now pay 20 cents at margin, but could get to 7.
- **“solar farms” on earth with mirror or lenses**: but breakthrough needed on cost... (JTEC or Stirling with Sandia dish solar)
- **24-hour energy from space** – new designs from NASA-NSF-EPRI offer a path to beating coal nuclear on cost with great hope of success... but new approach needed for low-cost access to space
- Need better (agile, international?) funding vehicle for high risk breakthrough TEAM B hopes, in diverse new areas as they arise...

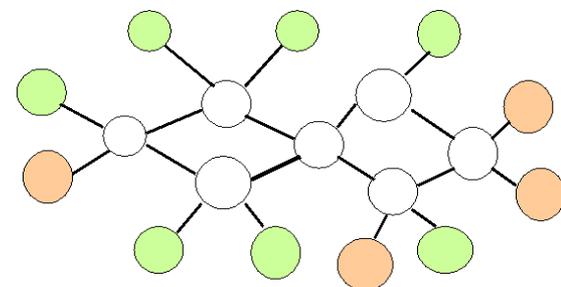


Dynamic Stochastic Optimal Power Flow (DSOPF): How to Integrate the “Nervous System” of Electricity

- DSOPF02 started from EPRI question: can we optimally manage&plan the whole grid as **one** system, with foresight, etc.?
- Closest past precedent: Momoh’s OPF integrates &optimizes many grid functions – but deterministic and without foresight. UPGRADE!
- ADP math required to add foresight and stochastics, critical to more complete integration.
- New work may deeply cut cost of hooking up solar (e.g. JTEC!) to electric power grids. Can we get do enough to get GE or ABB to follow through?



ANN to I/O From Idealized Power Grid



- ⌘ 4 General Object Types (busbar, wire, G, L)
- ⌘ Net should allow **arbitrary number** of the 4 objects
- ⌘ How design ANN to input and output FIELDS -- variables like the SET of values for current ACROSS all objects?

Why It Requires Artificial Neural Networks (ANNs)

- For optimal performance in the general nonlinear case (nonlinear control strategies, state estimators, predictors, etc...), we need to adaptively estimate nonlinear functions. Thus we must use **universal nonlinear function approximators**.
- Barron (Yale) proved basic ANNs (MLP) **much better** than Taylor series, RBF, etc., to approximate smooth functions of many inputs. Similar theorems for approximating dynamic systems, etc., especially with more advanced, more powerful, MLP-like ANNs.
- ANNs more “chip-friendly” by definition: Mosaix chips, CNN here today, for embedded apps, massive thruput

Optimization: Pick designs and controls so as to maximize future expected “utility U”



- We must decide what we want – “U”
- EPRI VP: “We want more than just pieces... they should all work together for maximum value..”
- Robustness versus resilience: maximize $\text{Pr}(\text{survival})$

But what is U for an electric Power grid?



- Many users, many “U” must be added up
- Multicriterion optimization fits well with new ADP
- If we agree on U and optimize it, we do better than the usual “Nash equilibrium” in the general case

Wunsch/venayagamoorthy/Harley ADP Turbogenerator Control



- Stabilized voltage & reactance under intense disturbance where neuroadaptive & usual methods failed
- Being implemented in full-scale experimental grid in South Africa
- Best paper award IJCNN99
- 1st of many, being deployed

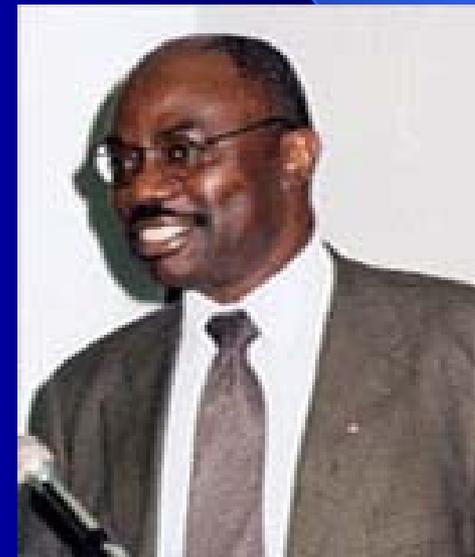
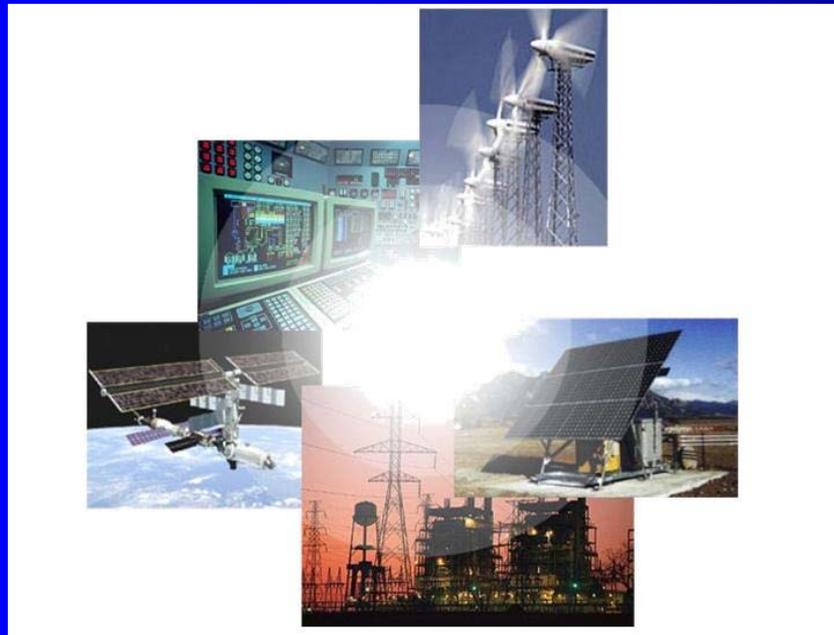
Neural Network in Commercial Power Grid Hardware



- First deployment of deployment of recurrent neural network in the field in a commercial electric power grid. (Improved prediction to allow unprecedented monitoring and control of harmonics.) Harley, Georgia Tech.

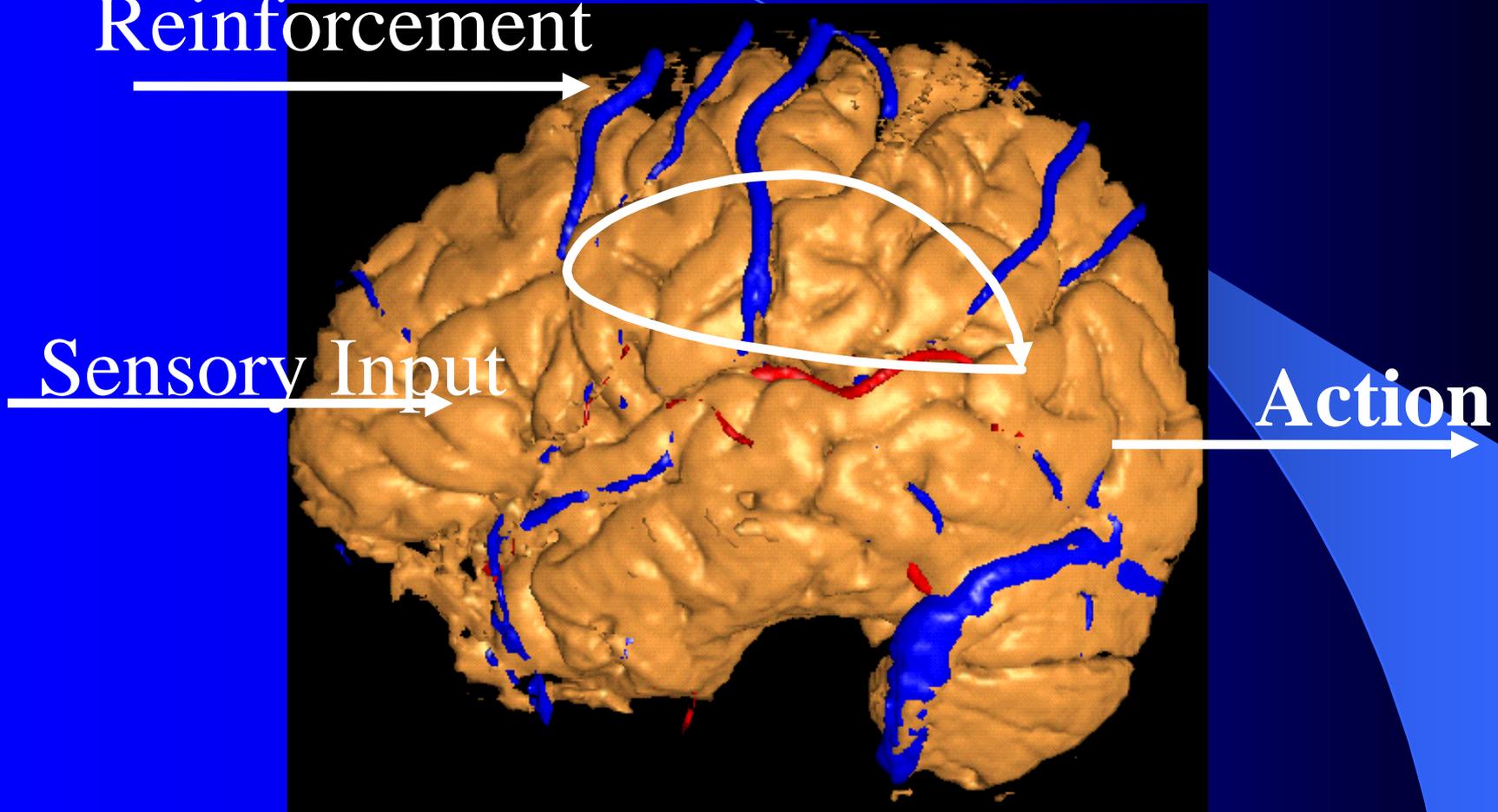
For More Information on DSOPF or
brain-style intelligence, see
www.eas.asu.edu/~nsfadp

See the Handbook Chapter on DSOPF by
James Momoh of Howard University...



www.cesac.howard.edu

Recent Progress in Developing Brain-Like Intelligent Control and Understanding the Brain Reinforcement



**The Brain As a Whole System
Is an Intelligent Controller**

“Cognitive Optimization and Prediction”, search on “COPN” at www.nsf.gov – and international follow-on?

$$\frac{\Pr(A|B) = \Pr(B|A) * \Pr(A) / \Pr(B)}$$

Prediction

Memory

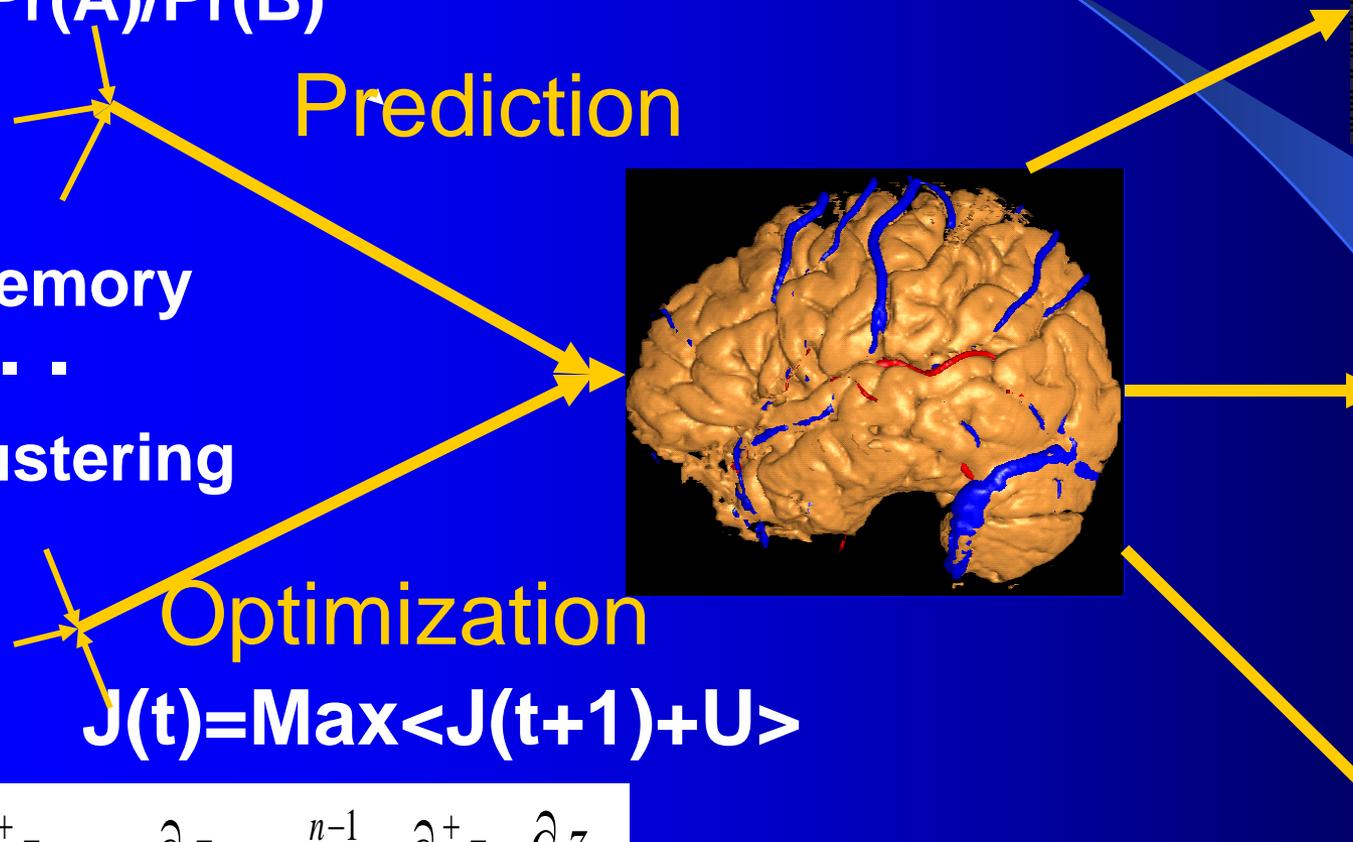
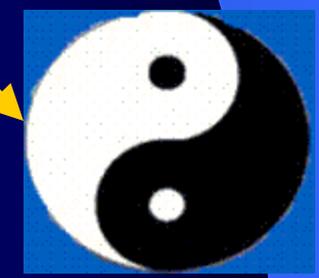
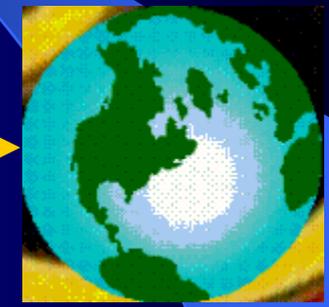
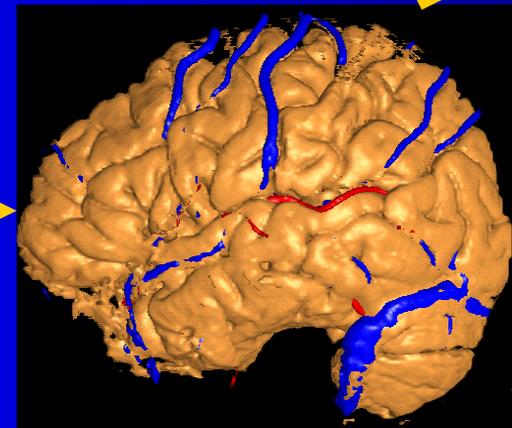
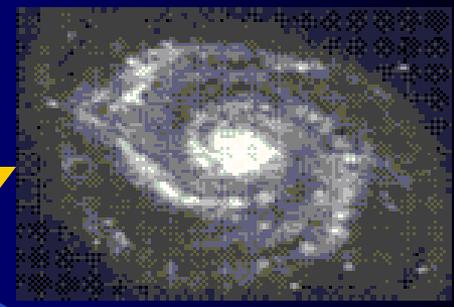
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Clustering

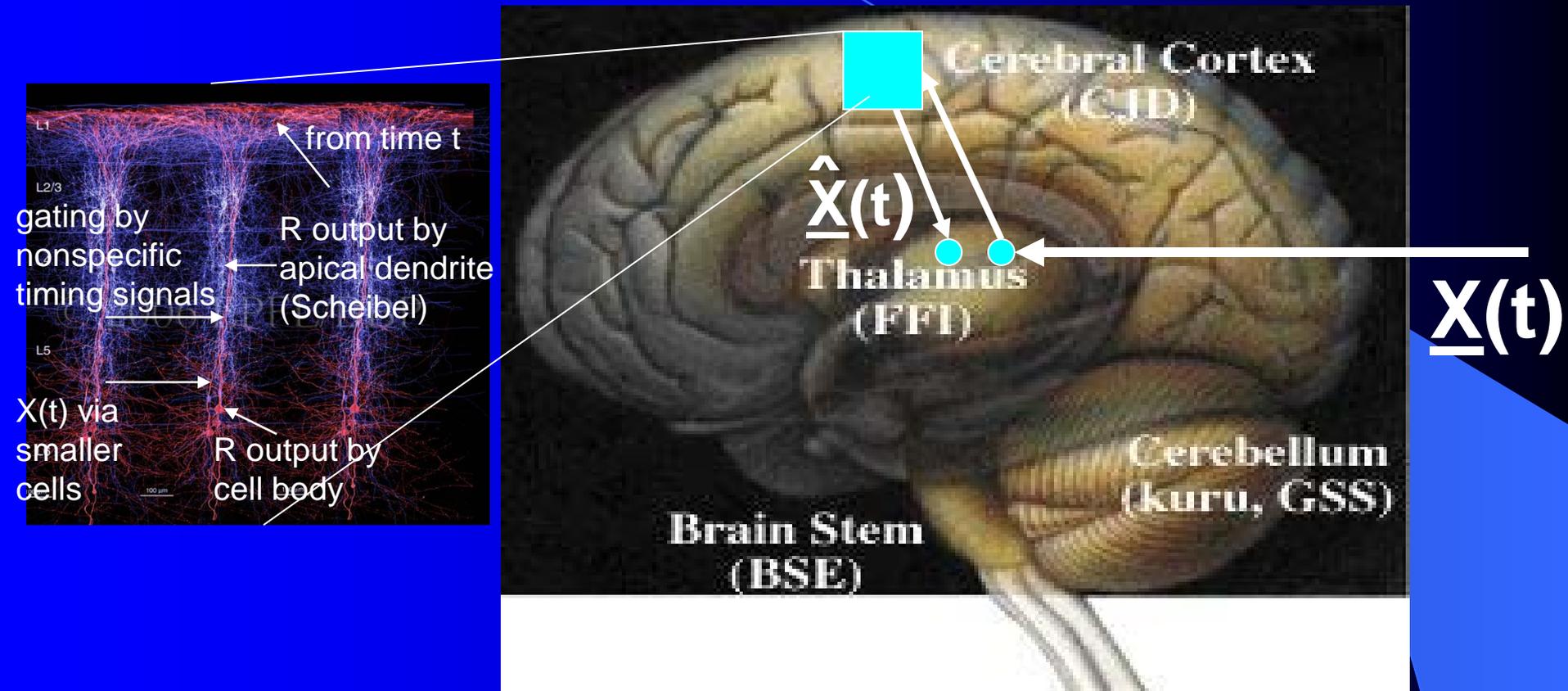
Optimization

$$J(t) = \text{Max} \langle J(t+1) + U \rangle$$

$$\frac{\partial^+ z_n}{\partial z_i} = \frac{\partial z_n}{\partial z_i} + \sum_{j=i+1}^{n-1} \frac{\partial^+ z_n}{\partial z_j} \frac{\partial z_j}{\partial z_i}$$



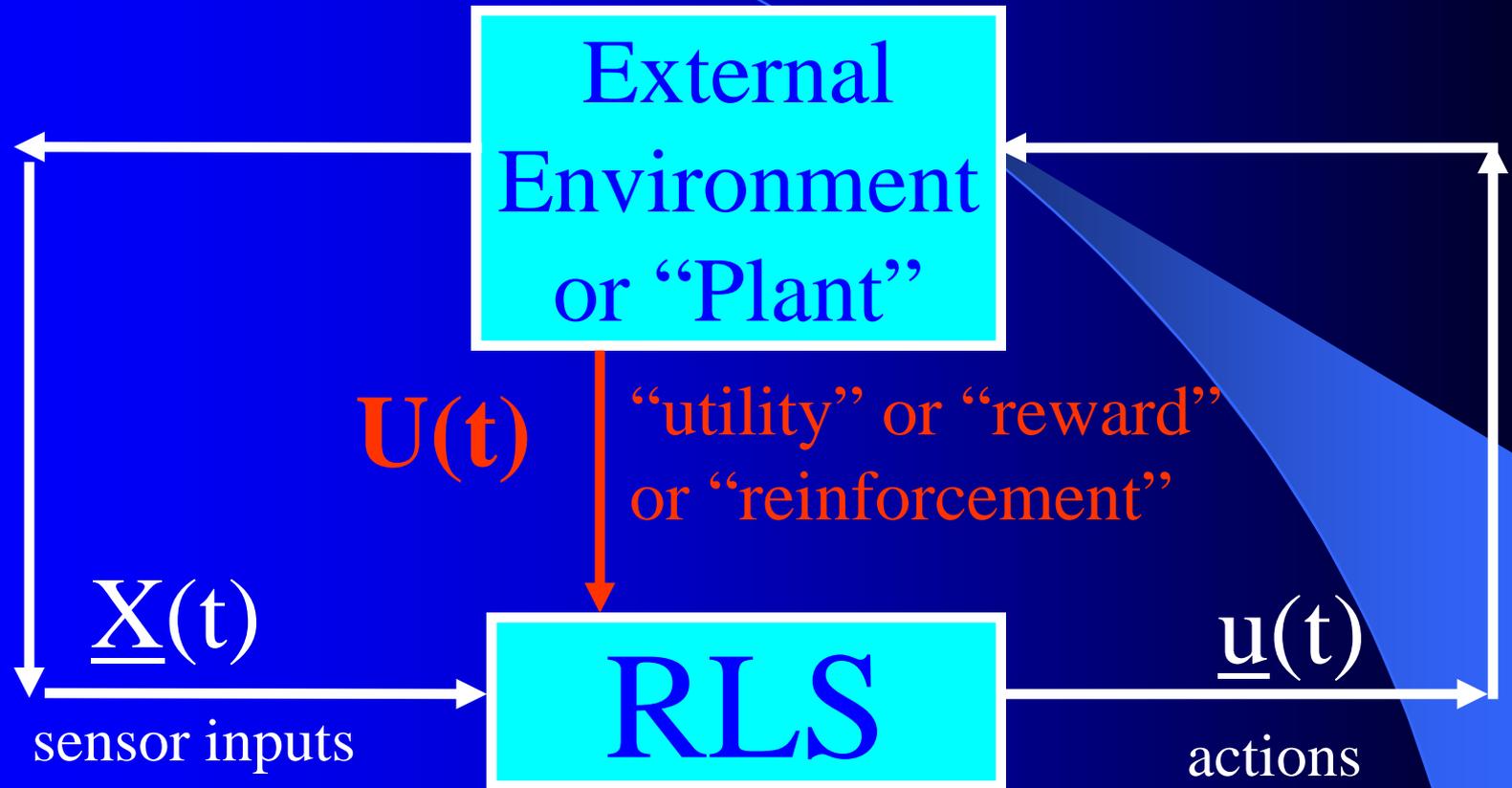
Ability to learn to “Predict Anything” Found in the Brain (Nicolelis, Chapin)



(Richmond): “t+1” – t is .12 seconds. Each cycle has a forwards pass to predict, and a backwards pass to adapt

(Bliss, Spruston): found “reverse nMDA” synapse and backpropagation along dendrites
BUT: needs demonstration for more than just rat whiskers! We need “COPN2”!

Reinforcement Learning Systems (RLS)



RLS may have internal dynamics and "memory" of earlier times $t-1$, etc.

Maximizing utility over time

Model of reality

Utility function U

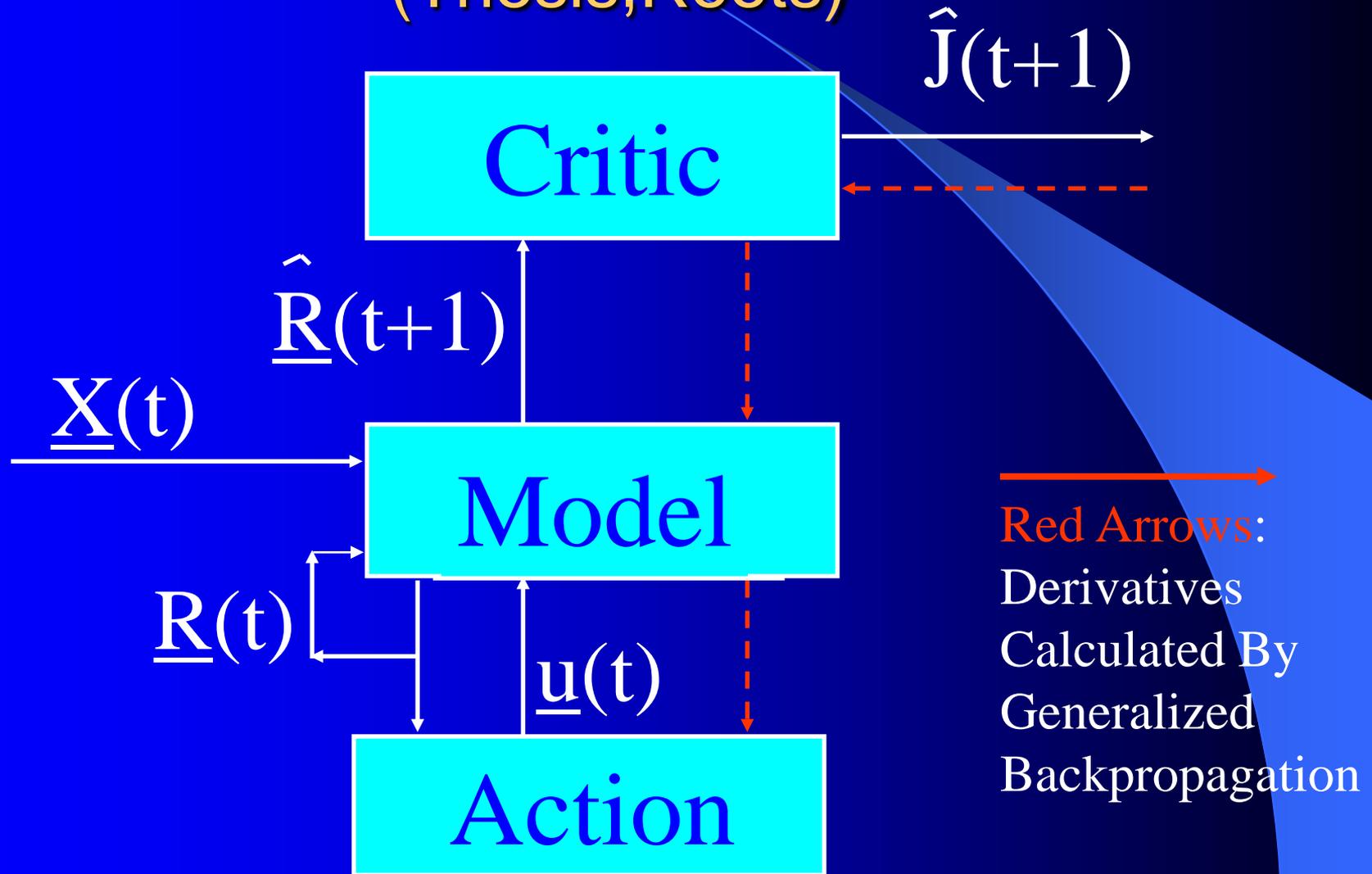
Dynamic programming

$$J(\mathbf{x}(t)) = \text{Max}_{\mathbf{u}(t)} \langle U(\mathbf{x}(t), \mathbf{u}(t)) + J(\mathbf{x}(t+1)) \rangle / (1+r)$$

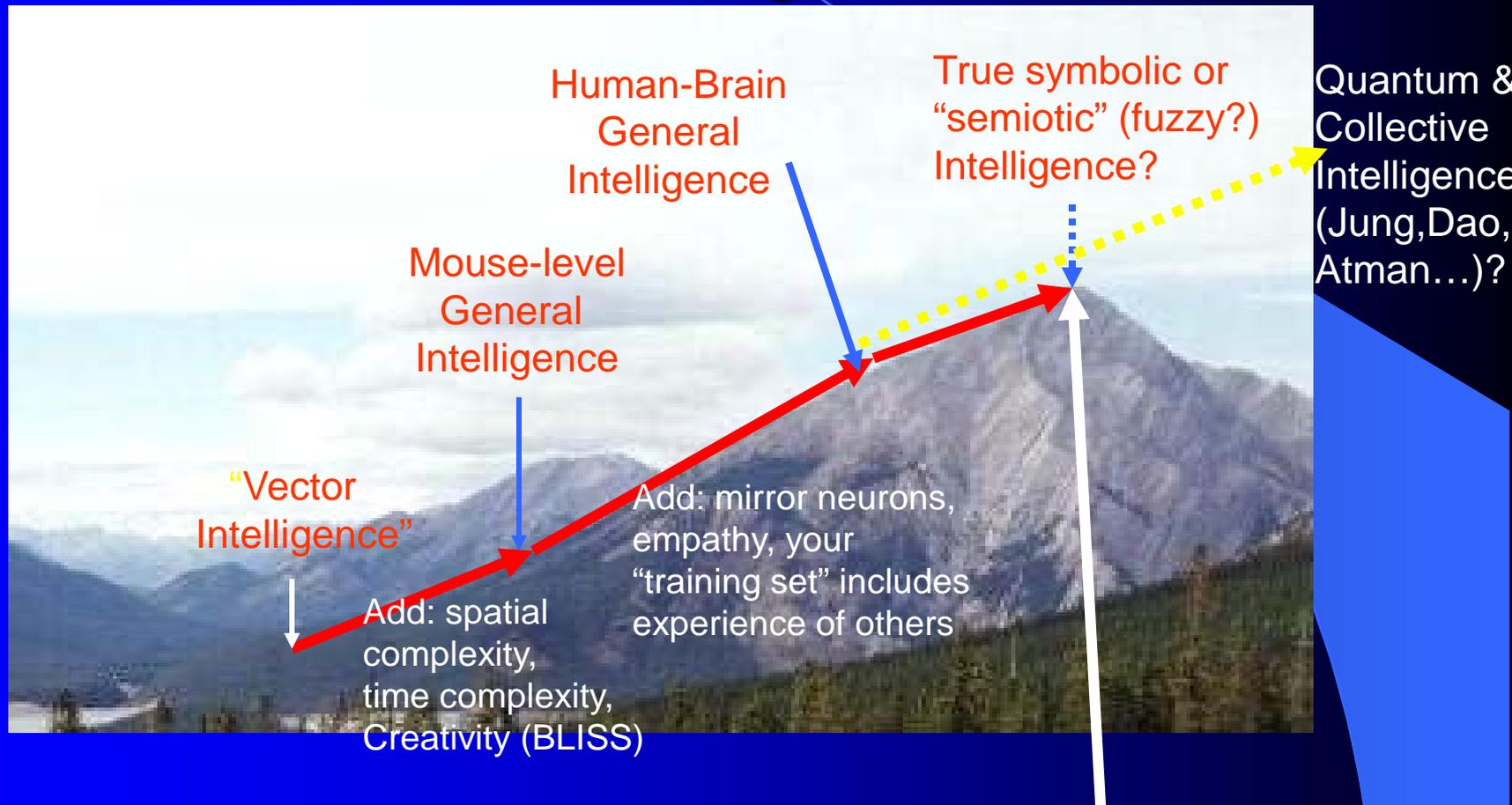
Secondary, or strategic utility function J

Sometimes called "value function V "

1971-2: Emergent Intelligence Is Possible If We Allow Three Types of Neuron (Thesis, Roots)



What is the Fastest and Most Promising Path to Build and Understand the Highest Level of Intelligence??



Straight Up the Cliff to “Human-Level” Intelligence?

David Fogel (Proc IEEE 2004): World's First System which LEARNED Master-Class Performance in Chess



- Evolutionary computing (EC) to train a game-player worked for tic-tac-toe, but not checkers
- EC to train a multilayer perceptron (MLP) to serve as a CRITIC (an ADP value function) was enough to beat checkers but not chess
- EC to train a feedforward Object Net as a Critic was enough to beat chess
- Prediction: A full (recurrent) ObjectNet Critic can get to master class in Go. Will Wunsch get there first?