Roadmap of Big data and AI Application in Nuclear Engineering

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May 17, 2017

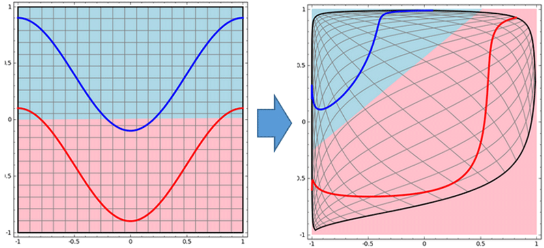
Mathematical modeling–major area

- Pattern recognition
- Function approximation
- Natural language processing

Linear vs. nonlinear

- Linear/nonlinear transformation or activation을 반복해 쌓아올린 구조
- 전통적 AI는 데이터 구분을 위한 선/공간을 왜곡해 합하는 구조

ex: blue vs. red 분리



Mathematical expression

- Nonlinear : $y = \sum_{i=1}^{N} f\left(a_i, x_i\right)$, neural network
- Linear & Linear–in–parameter : $y = \sum_{i=1}^{N} a_i x_i$
- Nonlinear but Linear–in–parameter : $y = \sum_{i=1}^{N} a_i f(x_i)$

Linear–in–parameter 의 장점 : Least Square 방법으로 a_i 쉽게 결정 가능

$$y = a_1 f(x_1) + a_2 f(x_2) + a_3 f(x_3)$$

$$y = [f]a, \quad \frac{\partial\{(y - [f]a)^2\}}{\partial a} = 0, \quad a = ([f]^T [f])^{-1} [f]^T y$$

Neural network은 Nonlinear–in–parameter system ⇒ difficult

Nonlinear but Linear in parameter : Thermal Design Procedure

$$y = \sum_{i=1}^{N} a_i f(x_i)$$

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \cdots + \sum_{i=1}^{k} \sum_{\substack{j=1 \\ i<j}}^{k} \beta_{ij} x_i x_j + \varepsilon$$

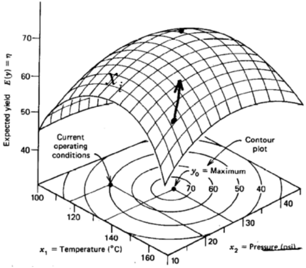
Temp., Pressure, Flow, ... : x_i

⇩

$\boxed{\text{Code}}$ $\sum_{i=1}^{N} a_i f(x_i)$

⇩

DNBR, LHR, ... : y

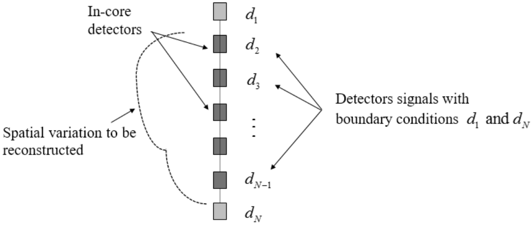


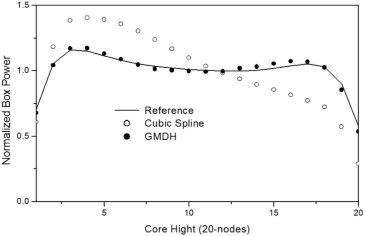
- Worst case identification으로 발전-[세종대학교 연구보고서] 보수적안전해석 방법론 안전여유도 타당성 평가 (2014, 원자력안전위원회)

Nonlinear and Linear in parameter : Incore Detector Signal

Multilayered iterative algorithm of Kolmogorov-Gabor or Ivakhnenko polynomial :

$$P(z) = a_0 + \sum_{i=1}^{N} a_i d_i + \sum_{i=1}^{N}\sum_{j=1}^{N} a_{ij} d_i d_j + \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{N} a_{ijk} d_i d_j d_k \cdots$$

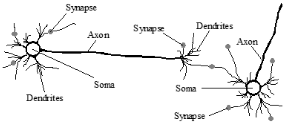


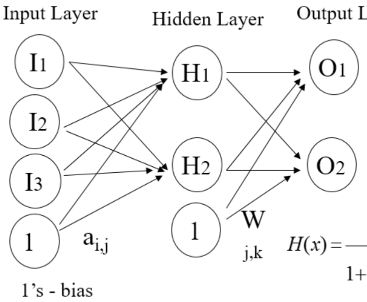


- Moon-Ghu Park, Ho-Cheol Shin, "Reactor power shape synthesis using Group Method of Data Handling," Nuclear Annals of Nuclear Energy 72 (2014)

Nonlinear & Nonlinear in parameter : Neural Network

$$y = \sum_{i=1}^{N} f(a_i, x_i)$$

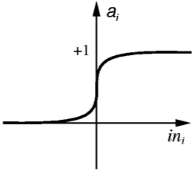




$$O(x) = \frac{1}{1+e^{-\sum_j a_{j,x} H_j}}$$

$$H(x) = \frac{1}{1+e^{-\sum_i a_{i,x} I_i}}$$

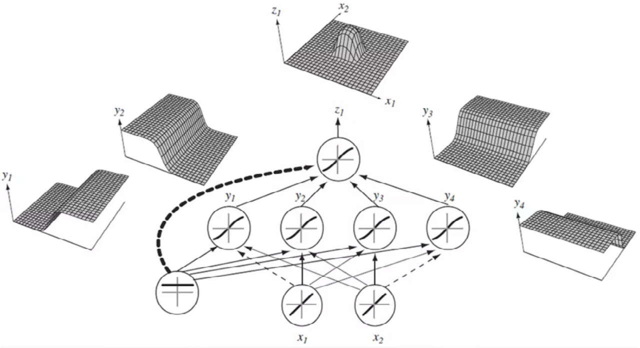
$$f(x) = \frac{1}{1+e^{-a\,x}}$$



Multi–layered back–propogation network

$\Rightarrow$ too difficult to learn when # of nodes and layers $\uparrow$.

- 어떠한 규칙으로 선을 긋고 공간을 왜곡할 것인가 ?
- 데이터를 활용 ⇒ 일단 대충 선을 긋고 구분 결과가 더 좋게 나오도록 조금씩 이동
- 즉, optimization과정이 필요한 데 Deep learning은 아주 많은 데이터와 오랜 시간의 최적화를 통해 데이터를 학습 (hardware 로 해결)
- 여러 개의 뉴런(linear+nonlinear)이 합쳐지면 복잡한 형상의 함수도 추정 가능



AlphaGo

- 바둑은 게임중에서도 극단적으로 계산량이 많음. (약 250^{150} 가지의 경우의 수)
- MCTS(Monte Carlo Tree Search) 이용하여 최적의 수 (Global Minimum) 탐색 가능
- MCTS도 너무 많은 계산시간 소요 $\Rightarrow$ 게임 트리를 탐색할 때 가능성이 높은 방향으로 탐색범위 조정 필요
- 가능성이 높은 방향을 짐작하기 위해 Policy Network : 정책 계산을 위한 딥러닝 신경망
- 이 정책이 반드시 승리로 가는 최적의 선택이라고 볼 수 없으므로 지도학습으로 구현된 정책 네트워크와 자체대결을 통해 결과적으로 승리하는 선택을 "강화"학습 (성을 계산 또는 추정하기 위해 가치(Value Network) 함수 도입
- 계산시간 단축은 강력한 Harware로 해결

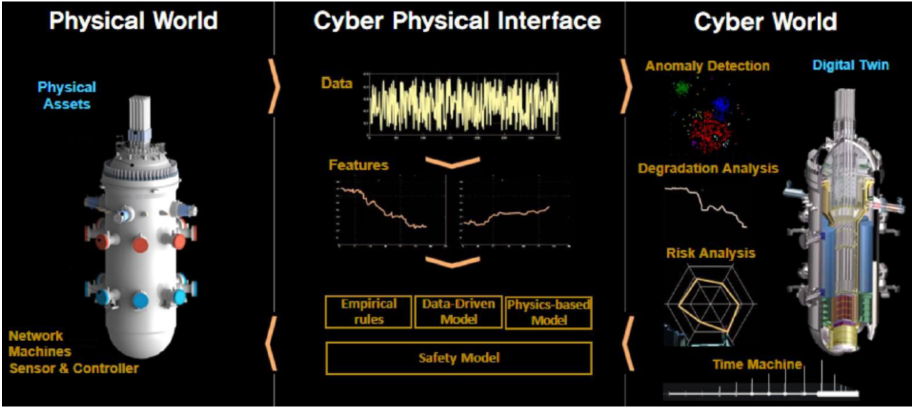
Open-world vs. Closed-world assumption

- In the OWA, statements about knowledge that are not included in or inferred from the knowledge explicitly recorded in the system may be considered unknown, rather than wrong or false. (Semantic Web languages such as OWL)
- CWA holds that any statement that is true is known to be true. Unknown statement is considered as false. (procedural programming languages and databases)

Concern for Safety Critical System

- Bartal, Yair *et al.*, "Nuclear power plant transient diagnostics using artificial neural networks that allow 'don't-know' classification," Nuclear Technology 110 (1995)
  - A nuclear power plant's (NPP's) status is usually monitored by a human operator. Any classifier system used to enhance the operator's capability to diagnose a safety-critical system like an NPP should classify a novel transient as 'don't-know' if it is not contained within its accumulated knowledge base. $\cdots$

Digital Twin

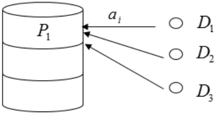


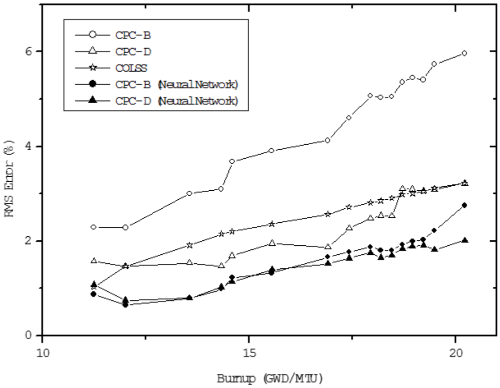
Transparency in Safety-Critical Systems

- In the field of safety-related applications it is essential to provide transparent solutions that can be validated by domain experts.
- Unfortunately, many of AI's most useful methods are among its least transparent.
- Support vector machines (SVMs) or artificial neural networks (ANNs) are known to achieve a high predictive performance but are usually hard to interpret.
- Fuzzy rule systems, decision trees, or linear models transparent but are usually limited with respect to their predictive performance.
- Programs should be intelligible and explicit, so that "what is going on" is not buried in the code or implicitly embodied in procedures.

Fitting with neural network : Excore Detector Signal (CPC)

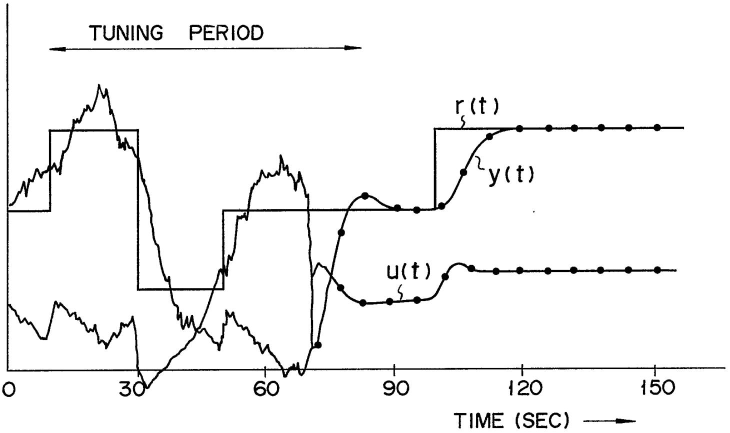
- The most robust methods tend to be the least transparent.
- Regulatory position so far : It is not transparent. $\Longrightarrow$ Should emphasize robustness.





Persistent Excitation

- Data-driven model has no rich excitation to learn complex dynamics.
- Excitation with multiple frequency inputs



AI & Open-World Complexity

- Known unknowns vs. unknown unknowns
- Decision making under uncertainty & incompleteness

Learn about abilities & failures

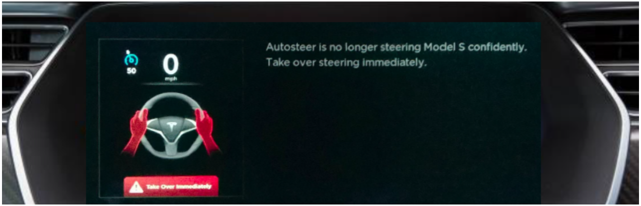
- Deep learning about deep learning performance
- Robustness via analytical portfolios or combination with transparent machine learning

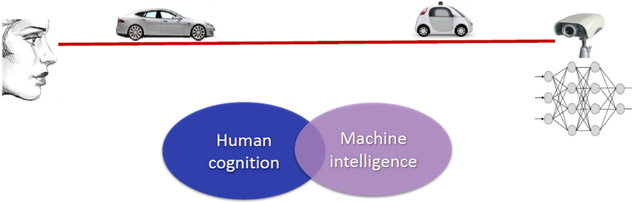
Learn about unknown unknowns

- Data, experience, rich simulations
- Human engagement
- Predict new distinctions, combine open- and closed-world models
- How to take fail-safe action

Human-machine collaboration

- Rich spectrum of autonomy
- How to best work together for safety?



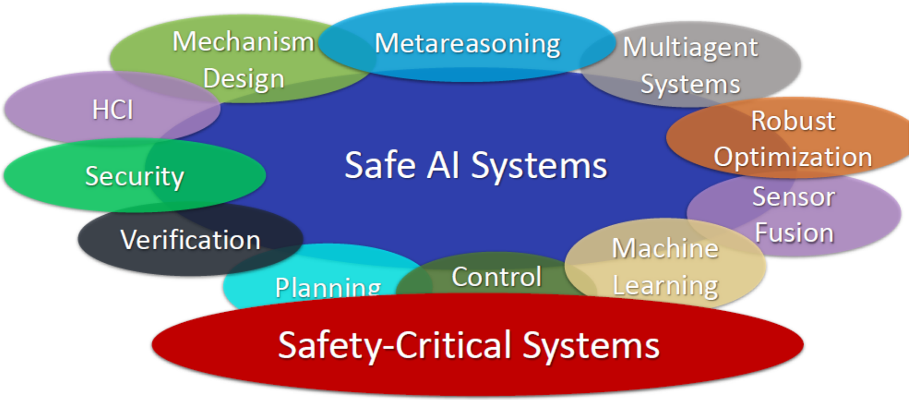


What Does AI Need ?

- Brain, right ?
  Assimov – I Robot Kubrick – HAL Jonze - Samantha

- Wrong!
- 이현세 만화 ‘아마게돈’
  완벽한 초자아컴퓨터 델타 8988 (?)
- Brain + Data!

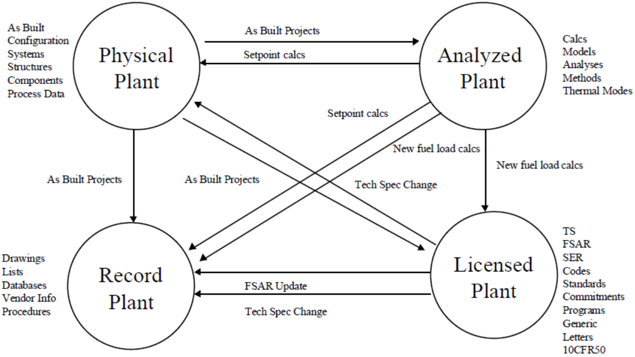
Relevance of Multiple Subdisciplines



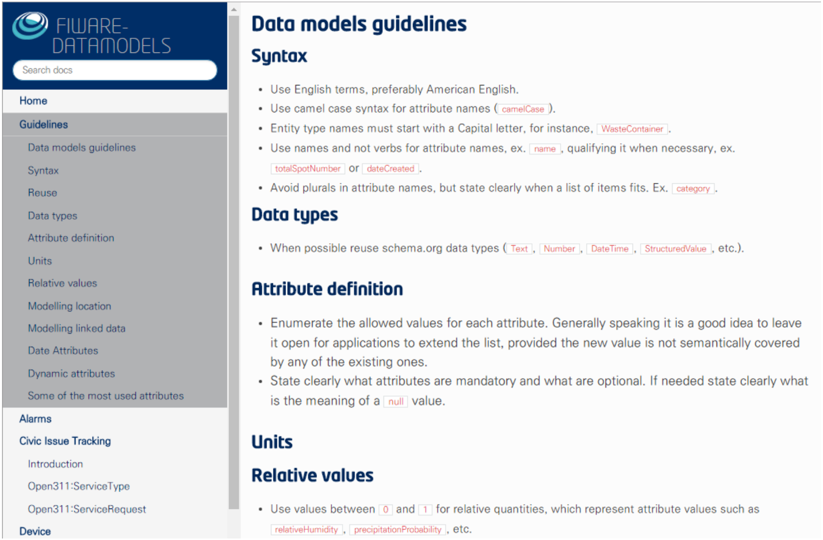
- Eric Horvitz, “Reflections on Safety and Artificial Intelligence,” Exploratory Technical Workshopon Safety and Control for AI (2016)

Deep NN + Big data + NLP + HW Power

- Law/Regulation, Standars, Papers, News....
- Tag/Metadata, graph DB, Semantic Web, Resource Description Framework, Ontology, Natural Language Processing
- Licensed Bases/Life–cycle Management



Data model



FIWARE-DATAMODELS

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Data models guidelines

Syntax

- Use English terms, preferably American English.
- Use camel case syntax for attribute names (`camelCase`).
- Entity type names must start with a Capital letter, for instance, `WasteContainer` .
- Use names and not verbs for attribute names, ex. `name` , qualifying it when necessary, ex. `totalSpotNumber` or `dateCreated` .
- Avoid plurals in attribute names, but state clearly when a list of items fits. Ex. `category` .

Data types

- When possible reuse schema.org data types (`Text` , `Number` , `DateTime` , `StructuredValue` , etc.).

Attribute definition

- Enumerate the allowed values for each attribute. Generally speaking it is a good idea to leave it open for applications to extend the list, provided the new value is not semantically covered by any of the existing ones.
- State clearly what attributes are mandatory and what are optional. If needed state clearly what is the meaning of a `null` value.

Units

Relative values

- Use values between `0` and `1` for relative quantities, which represent attribute values such as `relativeHumidity` , `precipitationProbability` , etc.

AI

- Intgrated & "knowledge pluggable" computer code system with "no interface data"
- New training tools including "Discrete Event System" modeling
- "Automated optimal integration" concept to plant design and non-compliance management
    - Evolutionary system design codes with neural net based optimization tools
    - Worst case identification in safety analysis and finding optimal operation condition in operation
    - Replace fitting functions to deep neural network for best–estimate measurement data
    - Deep neural network learning system dynamics for simulation, dynamic PSA, success criteria identification
- Identify "what are the AI can not do" things for safety critical system
- Autonomous operation of PGSFR (?)

Big Data

- Knowledge management system for Licensed Bases/Life–cycle Management
  - Big data analytics for regulation, licensing, paper, experiments, standards, best practice etc.
  - Licensing documents processing system with natural language processing
- Plant monitoring & IoT system
- Big data based security system
- Find "new, un–identified" safety concerns