Unlock Data to Optimize Industrial Processes

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EGI Technical Conference
Outline

• Trends in Data and Computing
• Data-Driven Engineering Tutorials
• Research Overview
• Conclusions
Current Trends in Data

Actual and forecast amount of data created worldwide 2010-2035 (in zettabytes)

25 GB/hour
150,000 points/sec
51,200 GB/hr

Source: Simafere, Fortune, RTInsights, Cisco
Current Trends in Data

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- 150,000 points/sec
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Source: Simafore, Fortune, RTInsights, Cisco
Current Trends in Computing

• +22% projected growth in programming jobs over next decade
  • Development, QA, Analysis, Testing

Source: Data is Beautiful Most Popular Programming Languages 1965 - 2022
Data-Driven Engineering

- Engineering Programming
- Optimization
- Machine Learning
- Dynamic Optimization
- Process Control
AI to Enhance HI (Human Intelligence)

Student-Teacher Ratio 1:30 to 1:1

Summative Achievement Scores

Salman Khan, TED Talk 2023
Brainstorm incentives for a customer loyalty program in a small book...

Plan a trip to explore the Madagascar wildlife on a budget

Make a content strategy for a newsletter featuring free local weekend e...

Come up with concepts for a retro-style arcade game
Generative AI for Prediction and Optimization

Learn

- Creating: Use info to create something new - design, build, plan, construct, produce, devise, invent
- Evaluating: Critically examine info & make judgements - judge, critique, test, defend, criticize
- Analyzing: Take info apart & explore relationships - categorize, examine, organize, compare/contrast
- Applying: Use info in a new (but similar) form - use, diagram, make a chart, draw, apply, solve, calculate
- Understanding: Understanding & making sense out of info - interpret, summarize, explain, infer, paraphrase, discuss
- Remembering: Find or remember info - list, find, name, identify, locate, describe, memorize, define

Apply

- Optimisation: What's the best that can happen?
- Predictive Modelling: What will happen next?
- Forecasting: What if these trends continue?
- Statistical Analysis: Why is this happening?
- Alerts: What actions are needed?
- Query Drilldown (OLAP): Where exactly is the problem?
- Ad-Hoc Reports: How many, how often, where?
- Standard Reports: What happened?

Business Analytics

Value

Business Intelligence

Synthesis
Data-Driven Engineering

Install Python
1 Basics
2 Tuple
3 List
4 Set
5 Dict
6 Numpy
7 Pandas
Python Introduction
NumPy

Python NumPy

- INSTALL + IMPORT
- 1D, 2D, 3D ARRAYS
- EXPORT + IMPORT
- UNARY OPERATIONS
- BINARY OPERATIONS

https://apmonitor.com/dde
### ChatGPT

**Examples**

- "Explain quantum computing in simple terms" →
- "Got any creative ideas for a 10 year old's birthday?" →
- "How do I make an HTTP request in Javascript?" →

**Capabilities**

- Remembers what user said earlier in the conversation
- Allows user to provide follow-up corrections
- Trained to decline inappropriate requests

**Limitations**

- May occasionally generate incorrect information
- May occasionally produce harmful instructions or biased content
- Limited knowledge of world and events after 2021

**ChatGPT Feb 13 Version. Free Research Preview. Our goal is to make AI systems more natural and safe to interact with. Your feedback will help us improve.**
Prompt Learning

• Help me find the error in my code without showing the answer.
• Explain each line of this Python code to a Matlab user.
• Generate a similar example.
• How can I make this more Pythonic?
• Test my knowledge of _Numpy.linspace_ with a quiz.
• Summarize what we’ve discussed so far.
• Translate this Python code to Matlab.
• I’m interested in ______. Why is this important to know?
• Generate a lesson plan on _Numpy_.


Data Import

1. Text
2. Audio
3. Video
4. Database
5. Sensors
6. Cloud
7. Web Scraping
Data Import and Access
Text Data Analysis

https://apmonitor.com/dde
Data-Driven Engineering

Engineering Programming

Machine Learning

Process Control

Optimization

Dynamic Optimization
Machine Learning for Engineers

https://apmonitor.com/pds
Machine Learning Roadmap
Data-Driven Modeling Languages

- scikit-learn
- tensorflow
- pytorch

Monthly Downloads

Year:
- 2017
- 2018
- 2019
- 2020
- 2021
- 2022

Example code snippet:
```python
# Define a list of classifiers
ns = [nb, LogisticRegression(), SGDClassifier(), KNeighborsClassifier(), DecisionTreeClassifier(), RandomForestClassifier(), SVC(), MLPClassifier(max_iter=2000), GradientBoostingClassifier(), XGBClassifier()]

c = 0
for clf in ns:
    print('Model:', clf)
    print('Accuracy:', clf.score(X, y))
```
Tubular Column

P

t, d

1

SCAN ME
ChatGPT

Examples

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"Got any creative ideas for a 10 year old's birthday?" →

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Column Design

Contours = Cost (objective)
Constraint line markers point towards feasible space.
Temperature Control Lab

apmonitor.com/heat.htm
Benchmark: Temperature Control Hardware
Data Availability

25 GB/hour

150,000 points/sec

51,200 GB/hr

Source: Simafore, Fortune, RTInsights, Cisco

Application: Flight Optimization

http://prismweb.groups.et.byu.net/360/

https://github.com/BYU-PRISM/hale-trajectory
Application: Biomechanics
MileSplit50: Jane Hedengren Moves To The No. 1 Spot

1. Jane Hedengren, Provo, UT
2. Elizabeth Leachman, Boerne, TX
3. Ellie Shea, MA
4. Sadie Engelhardt, Ventura, CA
5. Isabel Allori, Fort Collins, CO

LIVE EVENT COVERAGE
- 2023 Dave Sanders Invitational, 2023-09-22
- 2023 Live in Lou XC Classic, 2023-09-29
- 2023 FSU Pre-State Invitational, 2023-09-29
- 2023 McQuaid Invitational, 2023-09-30
Application: Drilling Automation
Physics-Informed, Data-Driven Modeling

Model Types

Linear
- FOPDT
- State Space
- Transfer Function
- ARX
- ARMAX
- Output Error
- FIR
- Box Jenkins
- Linearized Physics-Based

Nonlinear
- H-W
- Volterra
- NARX
- FF
- LSTM
- PINN
- Hybrid Models
- Physics-Based

Physics-Based

Linearized Physics-Based

Transformer
SysID Add-on Overview

Application
- Browser-based application
- Google-like search
- Tools for common functions
- Save and collaborate

Time Series Analytics
- Diagnostics analytics
- Monitoring and alerts
- Predictive analytics

Advanced Analytics
- Data cleansing
- Pattern recognition
- Scalable calculations
- Machine learning

pip install seeq-sysid
System Identification (SysID) Add-on

Models
- Time Series
- Subspace
- Neural Network
- Transfer Function
1. Select Data
2. Select Model
3. Identify
4. Push Model
Neural Network Models for Sequence Data

1986: RNN
1997: LSTM
2014: Seq2Seq
2015: Attention + Seq2Seq
2017: Transformer “Attention is all you need”
2018: GPT-1
2019: BERT
2020: GPT-3

NLP
Time-Series
TFT
AlphaGo
Attention Mechanism
Transformer Architecture (Self-attention)

- Short processing time
- No vanishing gradient
- Captures irregular temporal dependency
Model Predictive Control (Two options)

**Surrogate MPC**
- Trained by Open-loop data
- Fast (No optimization step)
- No online correction - can’t guarantee the performance

**Emulation MPC**
- Trained by Closed-loop data
- Fast (No optimization step)
- No online correction - can’t guarantee the performance
Training Data Preparation

Receding Window Snapshots

Number of Variables

Window (w)

Prediction Horizon (P)

Number of Snapshots (T)

$k-w$ $k$ $k+P$
Future of Data-Driven Control

- Short processing time
- No vanishing Gradient problem
- Capture irregular temporal dependency
Physics Informed Neural Network (PINN)

Training

\[ \text{MSE}_y = \frac{1}{N_y} \sum_{i=1}^{N_y} \left| y_{\text{NN}}(t_i, u_i) - y_{\text{meas}} \right|^2 \]

Evaluating

\[ \text{MSE}_f = \frac{1}{N_f} \sum_{i=1}^{N_f} \left| f(t_i, y_{\text{NN}}, y_{\text{NN}}, u_{\text{meas}}) \right|^2 \]

Combined Loss function
Physics Informed Neural Network (PINN)

PINN Off

PINN On