Oil & Gas Production Optimization in MATLAB

Leverage MATLAB’s powerful solvers for tackling nonlinear optimization problems

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MathWorks

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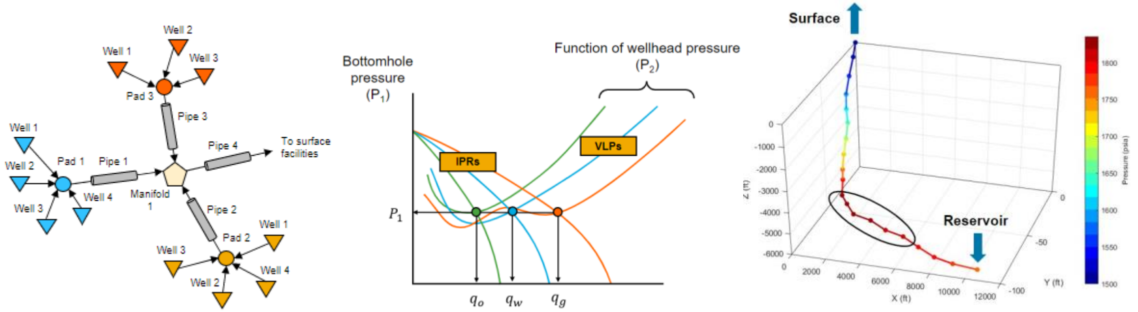

Artificial Intelligence | Big Data Analysis | Deep Learning | Machine Learning | Reinforced Learning | Predictive Analytics | Internet of Things | Process Optimization | Process Digitization | Process Automation | Value Chain Integration

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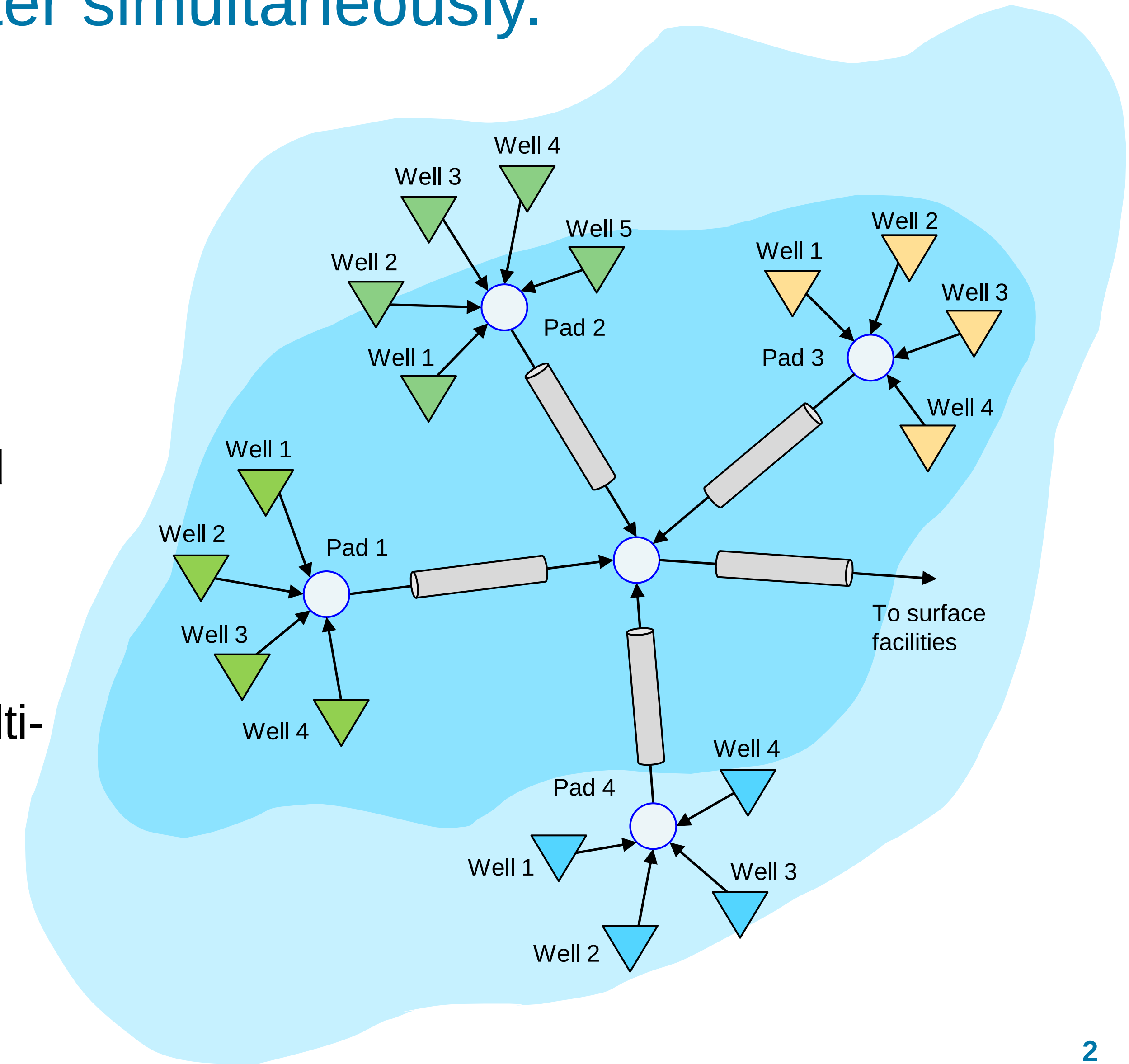
Accelerating the pace of engineering and science

For this analysis we will consider a four-pad multi-well production system producing oil, gas, and water simultaneously.

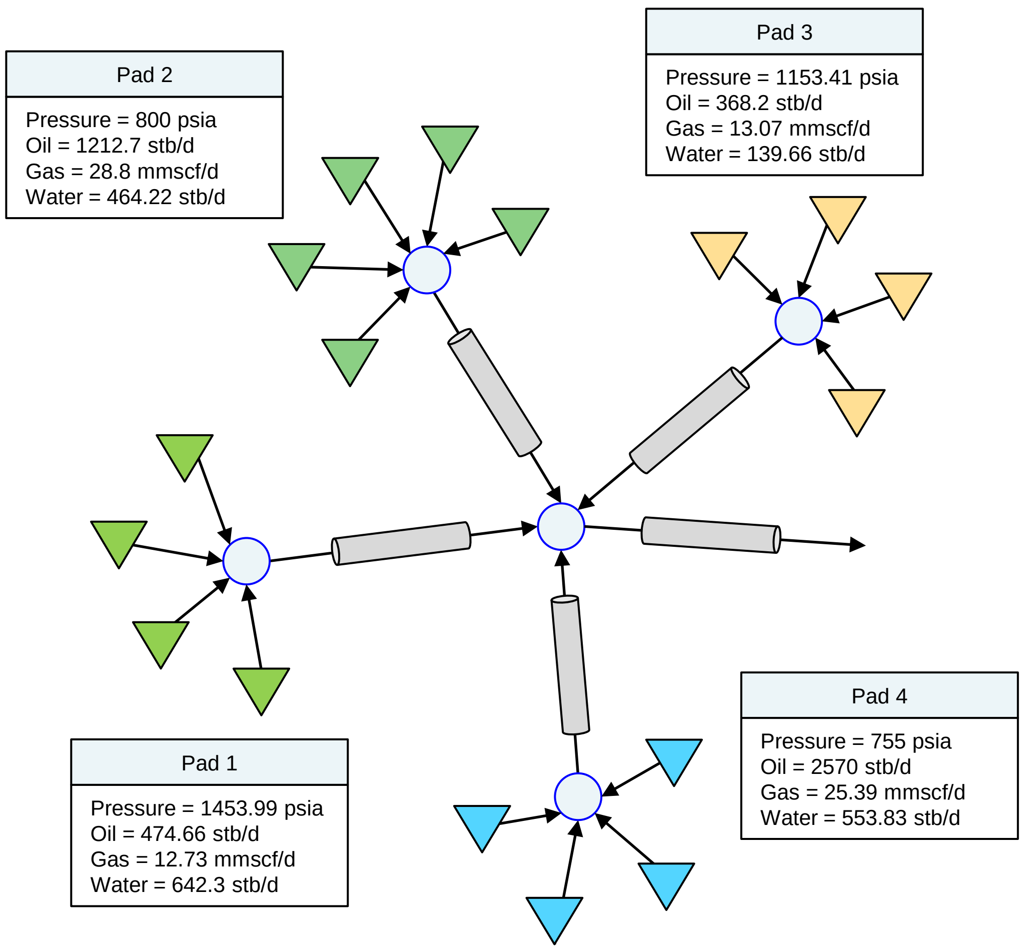
- Inflow Performance Relationship (IPR) and Vertical Lift Performance (VLP) data for each well are supplied via external simulation files.

- Downhole-to-surface conversion is performed over n-dimensional interpolating functions using an accelerated nonlinear solver.

- The goal of this use case is to establish a multi-purpose, robust, and maintainable production optimization workflow in MATLAB.



Case 1. Maximize oil production while keeping gas production between 40 and 80 MMSCFD and water production at or below 1800 STB/day.



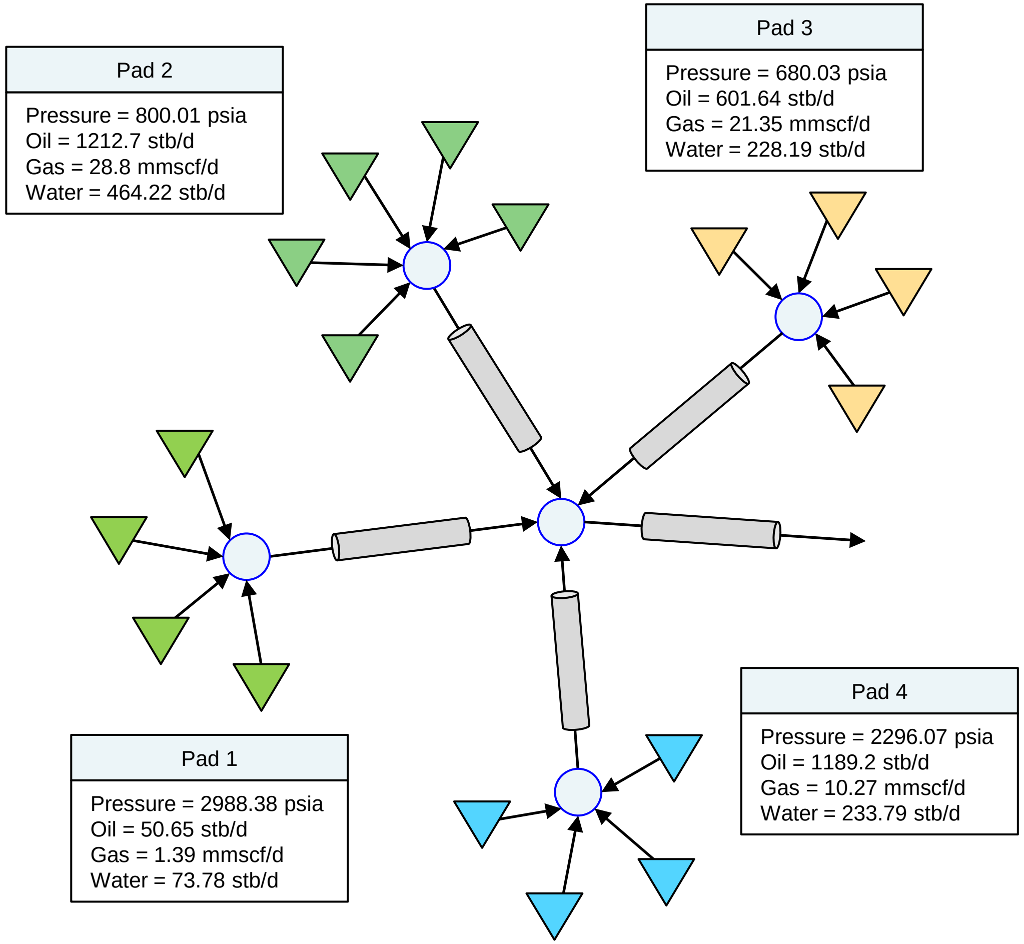
Optimization Model Summary

Pres	Pad 01	1453.99	psia
	Pad 02	800.00	psia
	Pad 03	1153.41	psia
	Pad 04	755.00	psia
	Oil rate	4625.61	BOPD
	Gas rate	80.00	MMSCFD
	Water rate	1800.00	BWPD

Per-pad / Per-well / Per-phase Optimization Results

Pad (ID)	Well (ID)	Oil Rate (BOPD)	Gas Rate (MMSCFD)	Water Rate (BWPD)
1	1	49.48	0.93	13.78
1	2	100.16	2.74	150.73
1	3	173.04	4.82	234.25
1	4	151.98	4.24	243.54
2	1	158.71	4.45	53.85
2	2	258.41	7.25	103.04
2	3	181.22	5.98	98.69
2	4	322.54	5.66	114.54
2	5	291.84	5.46	94.10
3	1	137.35	3.08	45.24
3	2	69.89	3.00	23.34
3	3	85.51	3.18	38.03
3	4	75.45	3.81	33.05
4	1	450.61	4.83	116.74
4	2	417.22	5.82	135.87
4	3	467.54	5.02	74.66
4	4	1234.65	9.72	226.56

Case 2. Maximize gas production while keeping water production at or below 1000 STB/day.



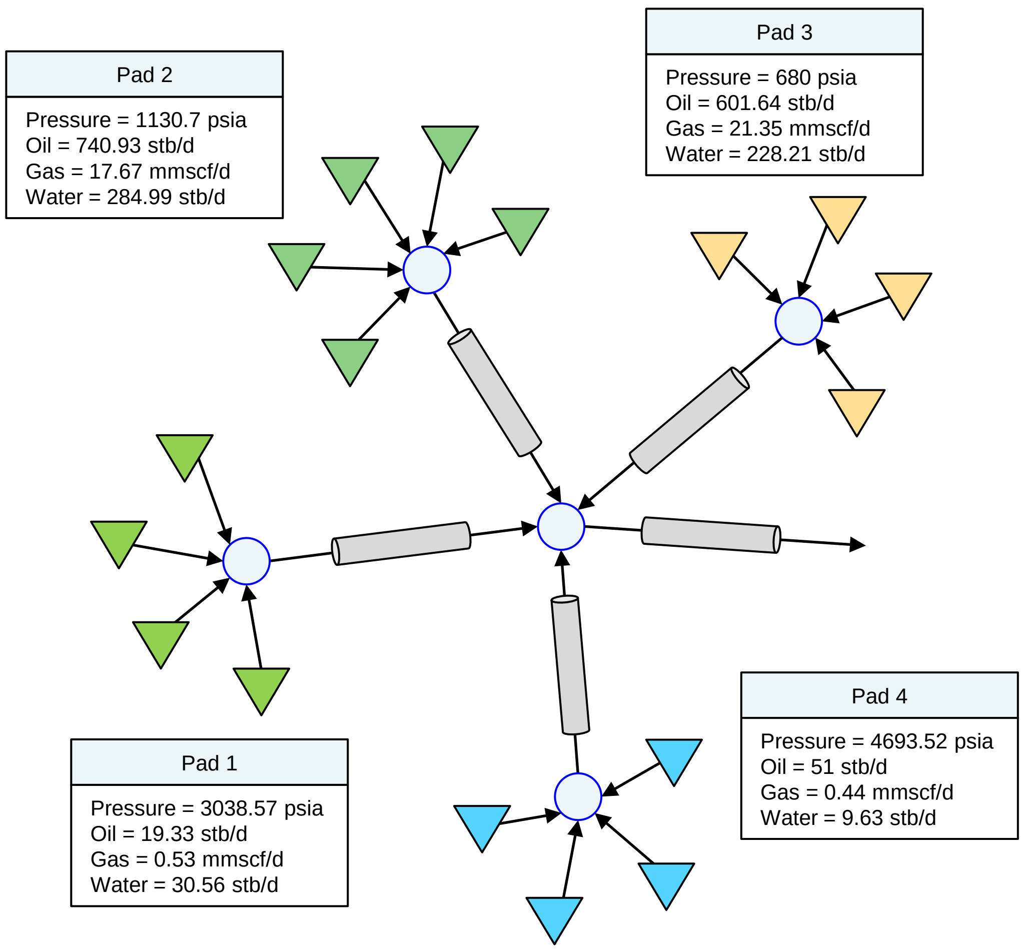
Optimization Model Summary

Pres	Pad 01	2988.38	psia
	Pad 02	800.01	psia
	Pad 03	680.03	psia
	Pad 04	2296.07	psia
Oil rate		3054.18	BOPD
Gas rate		61.81	MMSCFD
Water rate		1000.00	BWPD

Per-pad / Per-well / Per-phase Optimization Results

Pad (ID)	Well (ID)	Oil Rate (BOPD)	Gas Rate (MMSCFD)	Water Rate (BWPD)	
1	1	0.00	0.00	0.00	<- Well shut-in
1	2	0.00	0.00	0.00	<- Well shut-in
1	3	26.03	0.71	34.79	
1	4	24.62	0.68	38.99	
2	1	158.71	4.45	53.85	
2	2	258.41	7.25	103.04	
2	3	181.21	5.98	98.69	
2	4	322.54	5.66	114.54	
2	5	291.84	5.46	94.10	
3	1	226.22	5.08	74.42	
3	2	110.10	4.75	36.73	
3	3	147.72	5.53	65.58	
3	4	117.60	5.99	51.46	
4	1	74.82	0.79	19.24	
4	2	77.24	1.08	25.01	
4	3	97.77	1.04	15.55	
4	4	939.36	7.36	173.99	

Case 3. Minimize water production while keeping gas production between 40 and 80 MMSCFD.



Optimization Model Summary

Pres	Pad 01	3038.57	psia
	Pad 02	1130.70	psia
	Pad 03	680.00	psia
	Pad 04	4693.52	psia
	Oil rate	1412.91	BOPD
	Gas rate	40.00	MMSCFD
	Water rate	553.38	BWPD

Per-pad / Per-well / Per-phase Optimization Results

Pad (ID)	Well (ID)	Oil Rate (BOPD)	Gas Rate (MMSCFD)	Water Rate (BWPD)	
1	1	0.00	0.00	0.00	<- Well shut-in
1	2	0.00	0.00	0.00	<- Well shut-in
1	3	0.00	0.00	0.00	<- Well shut-in
1	4	19.33	0.53	30.56	
2	1	105.92	2.97	35.98	
2	2	153.89	4.28	61.47	
2	3	116.16	3.83	63.29	
2	4	194.61	3.41	69.24	
2	5	170.35	3.18	55.01	
3	1	226.22	5.08	74.43	
3	2	110.10	4.75	36.74	
3	3	147.72	5.53	65.58	
3	4	117.60	5.99	51.46	
4	1	0.00	0.00	0.00	<- Well shut-in
4	2	0.00	0.00	0.00	<- Well shut-in
4	3	0.00	0.00	0.00	<- Well shut-in
4	4	51.00	0.44	9.63	

Agenda

- Outline and define production optimization problem
- Introduction to the Optimization Toolbox
- Prepare and set up optimization problem
  - Improving mathematical model with heuristics
  - Problem-based optimization workflow in MATLAB
- Deploying optimization models
- Key takeaways

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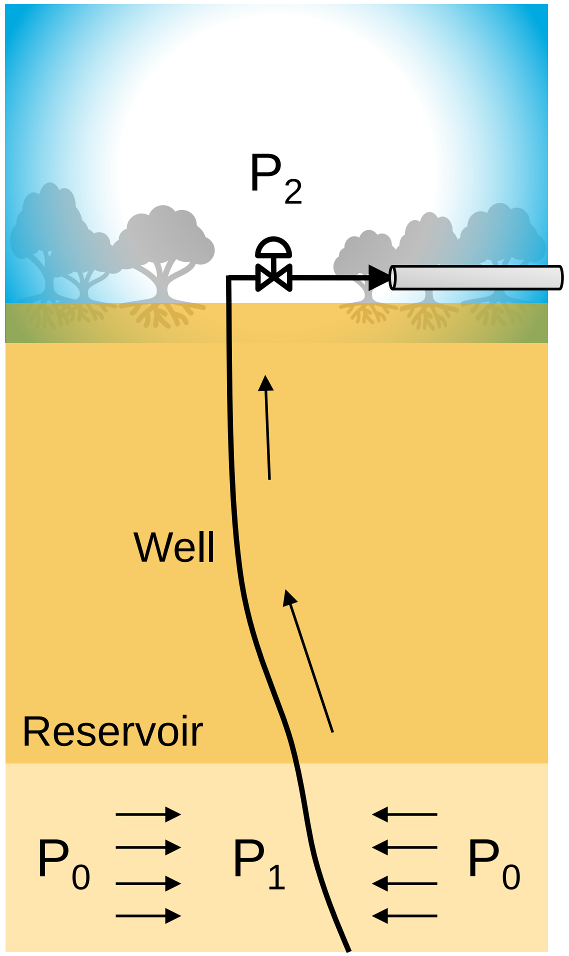
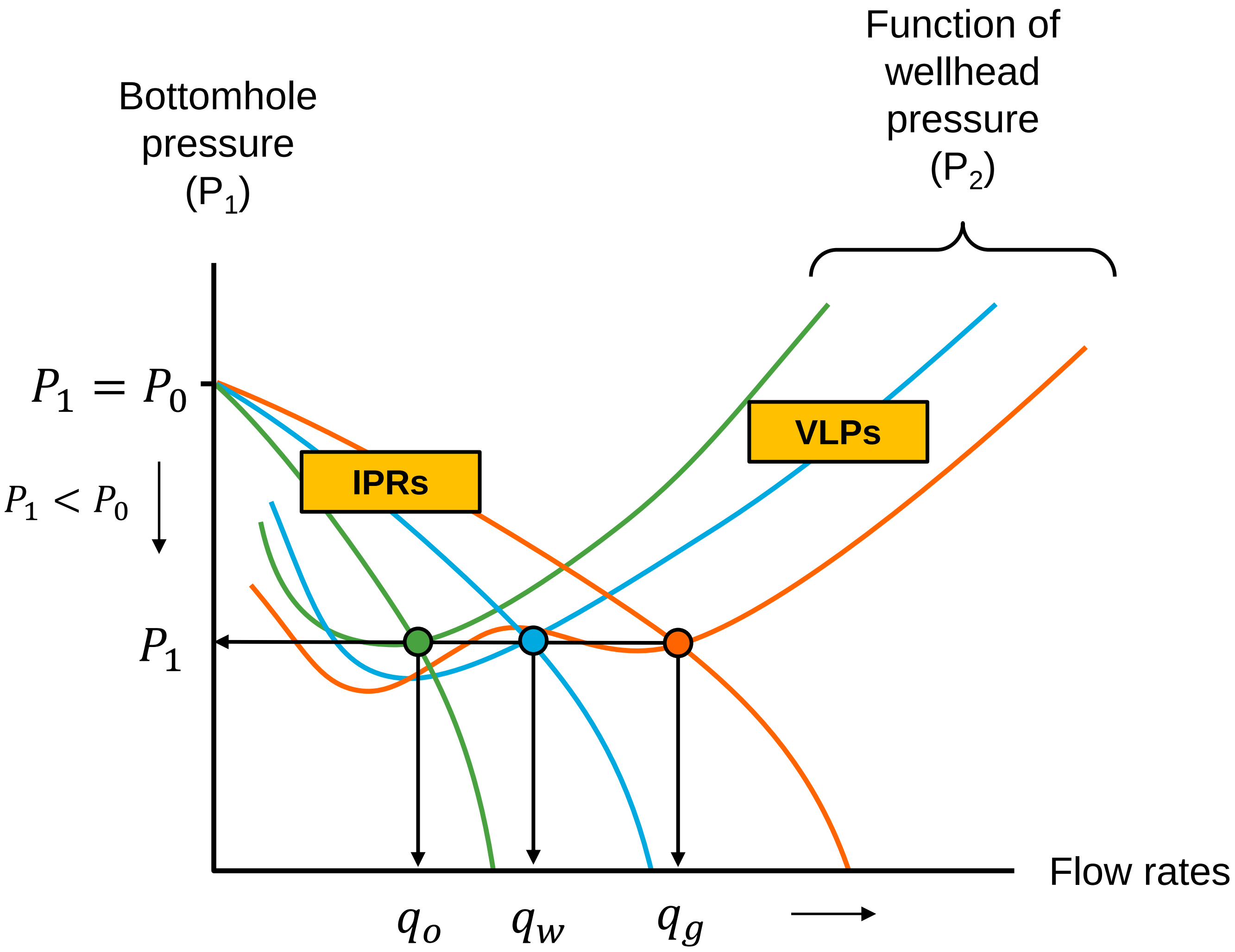
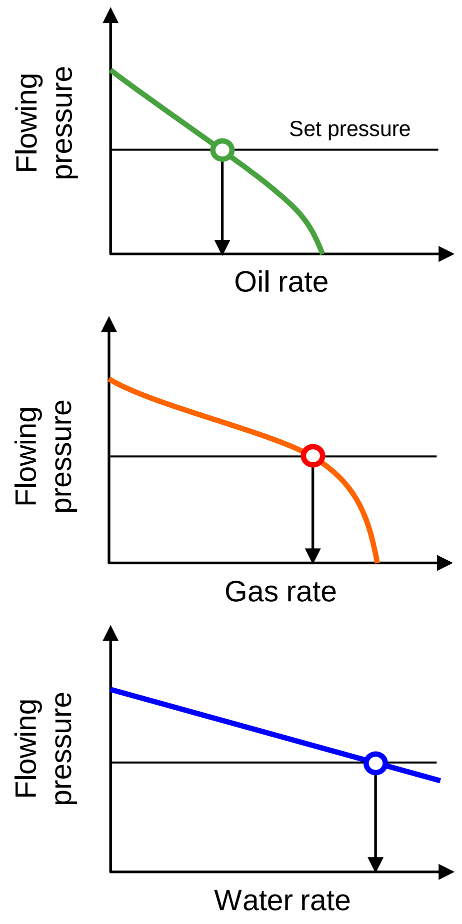
The surface-to-downhole conversion part of the model is critical to solve the production optimization problem.



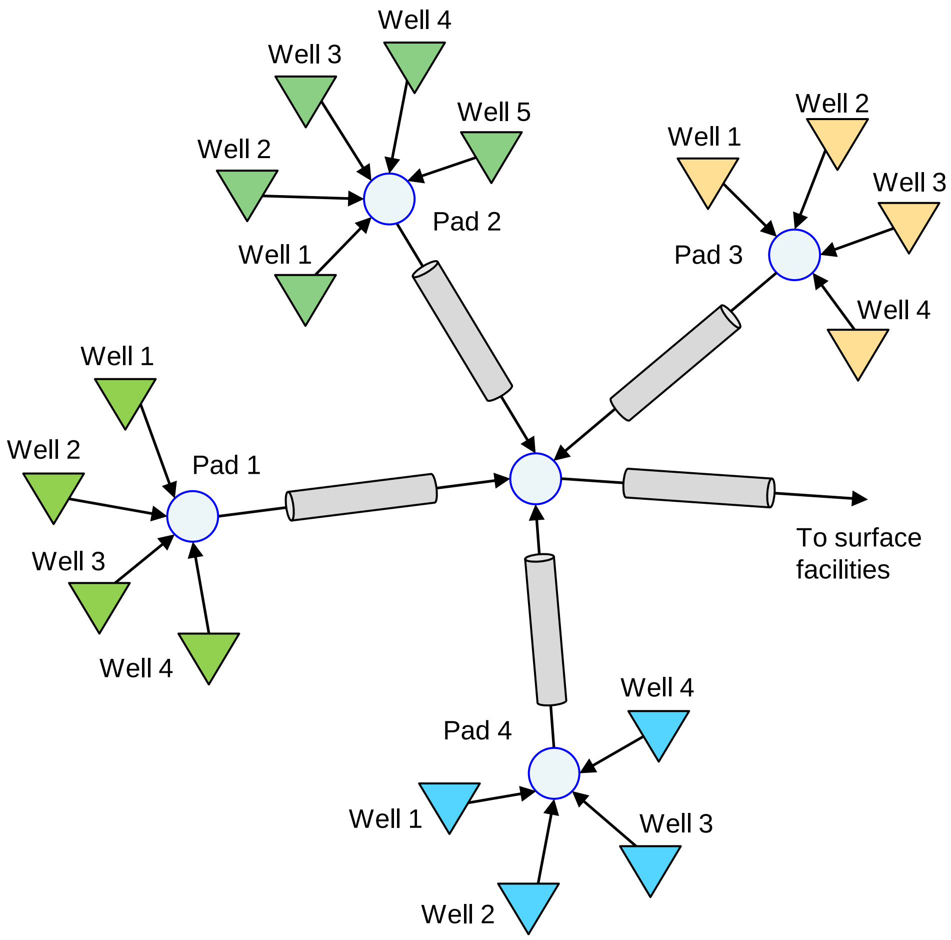


This case study considers production optimization of several multi-well pads interconnected via pipes and manifolds.

Inflow Performance Relationship (IPR)



$\mathbf{q}$ = <oil rate, gas rate, water rate>



Pad 1

Well 1	Well 2	Well 3	Well 4
$\mathbf{q}_{11} = f_{11}(p)$	$\mathbf{q}_{21} = f_{21}(p)$	$\mathbf{q}_{31} = f_{31}(p)$	$\mathbf{q}_{41} = f_{41}(p)$

Assuming equal pressure $p = p_1$ for all wells in the pad

Total production rates

$$\mathbf{q}_1 = f_{11}(p_1) + f_{21}(p_1) + f_{31}(p_1) + f_{41}(p_1) = F_1(p_1)$$

Each pad has its own lumped production function

Multi-pad system

Pad 1	Pad 2	Pad 3	Pad 4
$\mathbf{q}_1 = F_1(p_1)$	$\mathbf{q}_2 = F_2(p_2)$	$\mathbf{q}_3 = F_3(p_3)$	$\mathbf{q}_4 = F_4(p_4)$

Pressure on each pad is independent from one another

Total system production

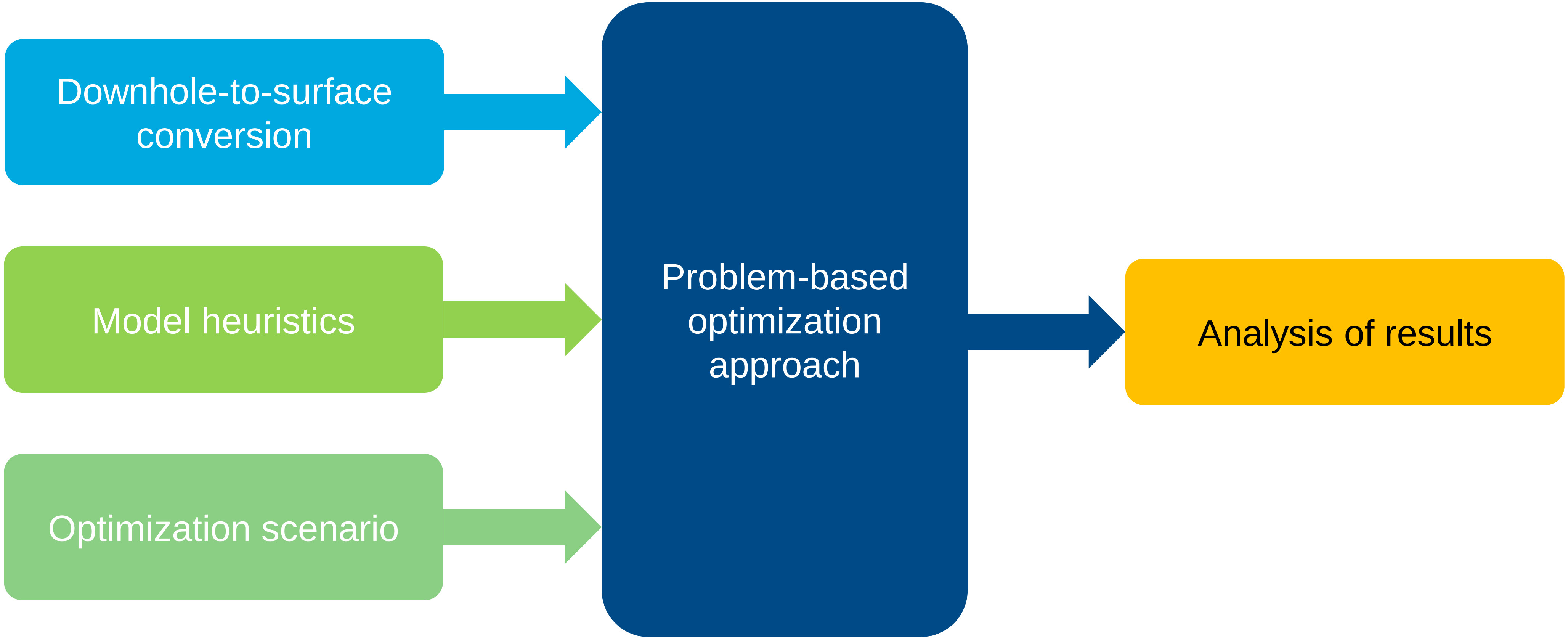
$$\mathbf{q}_t = F_1(p_1) + F_2(p_2) + F_3(p_3) + F_4(p_4)$$

This case study considers production optimization of several multi-well pads interconnected via pipes and manifolds.

General all-pads problem
$\mathbf{q}_t = F(\mathbf{p}) = \sum F_i(p_i)$

- Straightforward problem formulation
  - Supply pressure vector (input), get total rate vector (output)
  - Meant to answer direct questions like “how much will we produce if **p** = <p_1, p_2, p_3, … , p_k>?”
- Inverse-problem formulation is quite difficult
  - Tightly coupled problem; *N*-degrees of freedom
  - Extremely challenging to answer “is there any **p** for which **q** equals…?”
- ★ Optimization problem setup
  - Seeks to solve questions like “what pressures do we need in order to maximize oil production while keeping water production between *x* and *y*?”

We can solve the all-pads optimization problem following a problem-based approach in MATLAB.



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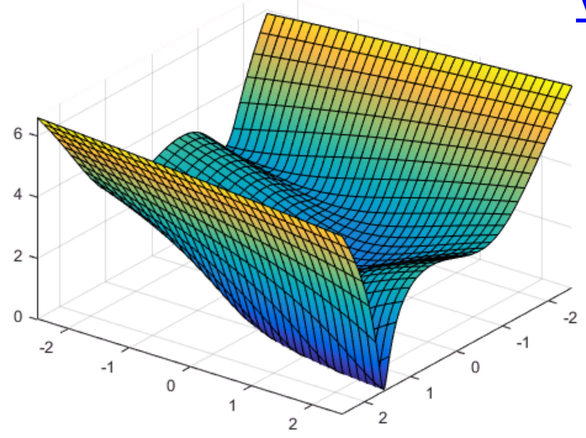
MathWorks Optimization Products

- **Optimization Toolbox**
  – Functions for finding parameters that **minimize or maximize objectives** while **satisfying constraints**

video



Objective with single minimum

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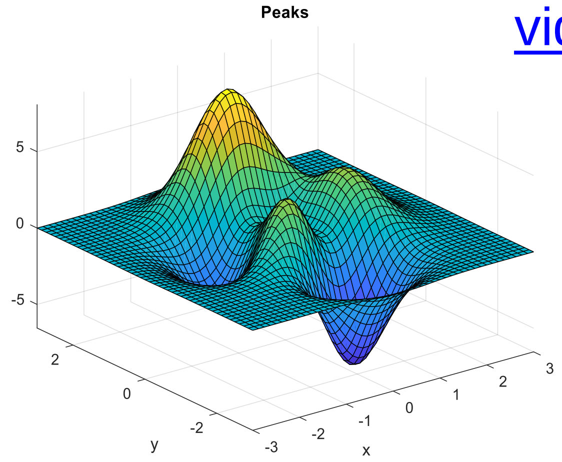
- **Global Optimization Toolbox**
  – Functions that **search for global solutions** to problems that contain **multiple maxima or minima** on **smooth or nonsmooth** problems *(requires Optimization Toolbox)*

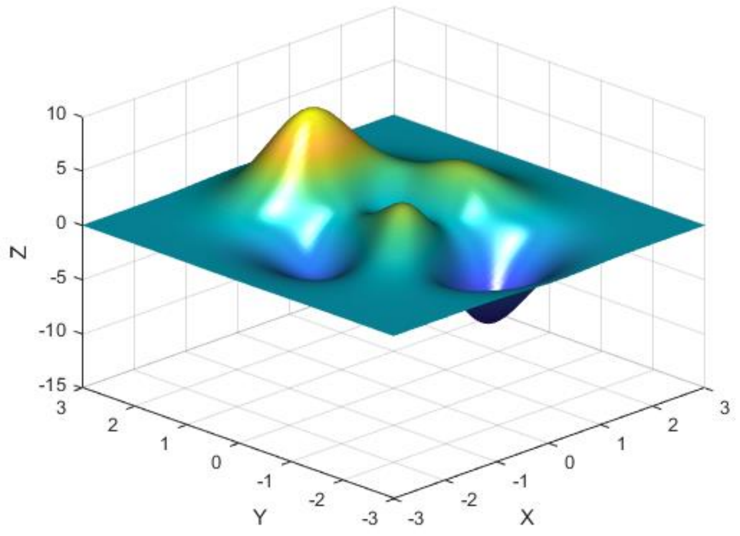
video

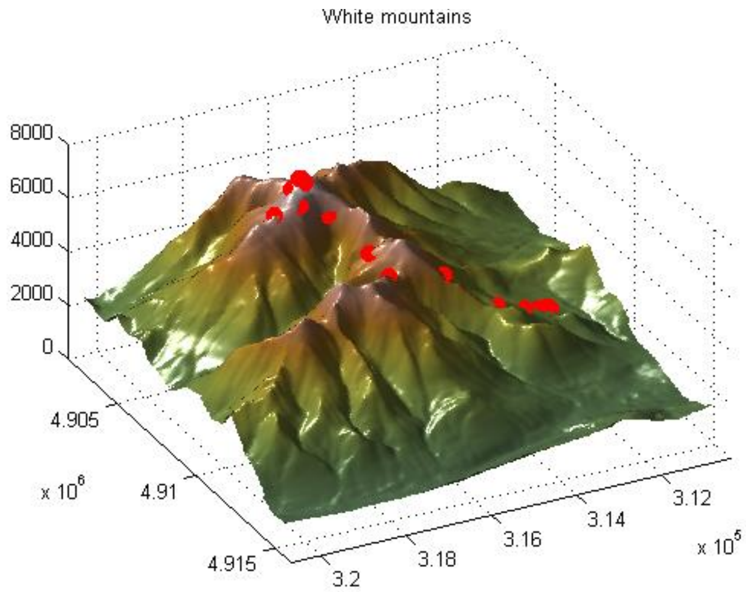


Objective with multiple minima

Optimization toolboxes support different problem types

	Optimization Toolbox	Global Optimization Toolbox
Faster	✓	
Large Problems	✓	
Better on: • Nonsmooth • Noisy • Stochastic • Highly nonlinear		✓
More “global”		✓
Custom data types		✓

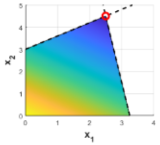


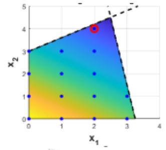


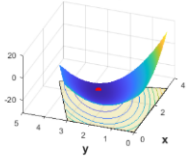
Solving: Problem Types and Algorithms

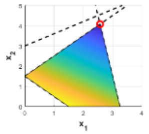
Optimization Toolbox

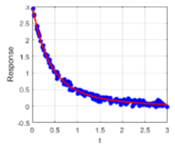
Global Optimization Toolbox

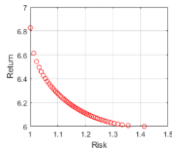




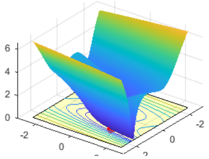


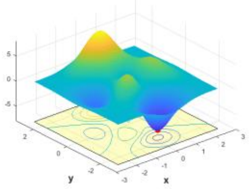


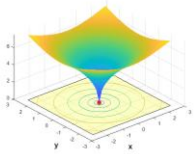




- Linear programming
  - Simplex and interior-point
- Mixed-integer linear programming
  - Branch-and-cut
- Quadratic programming
  - Interior-point, active-set, trust-region
- Second-order cone programming
  - Interior-point
- Least-squares and nonlinear equations
  - Interior-point, trust-region, Levenberg-Marquardt
- Multiobjective optimization
  - Weighted and goal-attainment
  - *Genetic algorithm*
  - *Paretosearch*







- Nonlinear optimization
  - Nelder-Mead simplex
  - Interior-point, SQP, trust-region
  - *MultiStart & GlobalSearch*
  - *Pattern (direct) search*
  - *Genetic algorithm*
  - *Simulated annealing*
  - *Particle swarm*
  - *Surrogate optimization*
- Mixed-integer nonlinear optimization
  - *Genetic algorithm*
  - *Surrogate optimization*

Optimization Decision Table

Solve many types of optimization problems with MATLAB

Optimization Toolbox
Global Optimization Toolbox

Constraint Type	Objective Type					
	Linear	Quadratic	Least Squares	Smooth nonlinear	Nonsmooth	Multiobjective
None		quadprog	lsqcurvefit lsqnonlin	fminsearch fminunc	fminsearch *ga*	fgoalattain fminimax *paretosearch* *gamultiobj*
Bound		quadprog	lsqcurvefit lsqnonlin lsqnonneg lsqlin	fmincon	fminbnd *ga* *surrogatopt* *patternsearch* *particleswarm* *simulannealbnd*	fgoalattain fminimax *paretosearch* *gamultiobj*
Linear	linprog	quadprog	lsqlin	fmincon	*ga* *patternsearch* *surrogatept*	fgoalattain fminimax *paretosearch* *gamultiobj*
Second-Order Cone	coneprog	coneprog				
General smooth	fmincon	fmincon	fmincon	fmincon	*ga* *patternsearch* *surrogateopt*	fgoalattain fminimax *paretosearch* *gamultiobj*
General nonsmooth	*ga* *patternsearch*	*ga* *patternsearch*	*ga* *patternsearch*	*ga* *patternsearch*	*ga* *patternsearch* *surrogateopt*	*paretosearch* *gamultiobj*
Discrete	intlinprog				*ga* *surrogateopt*	

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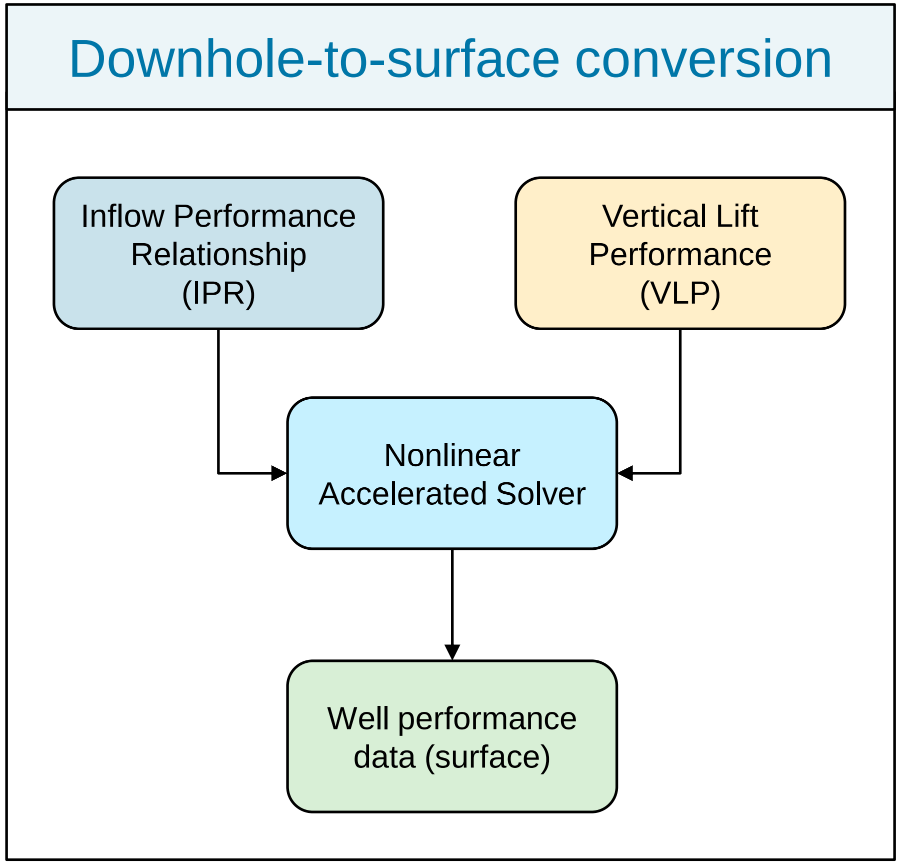
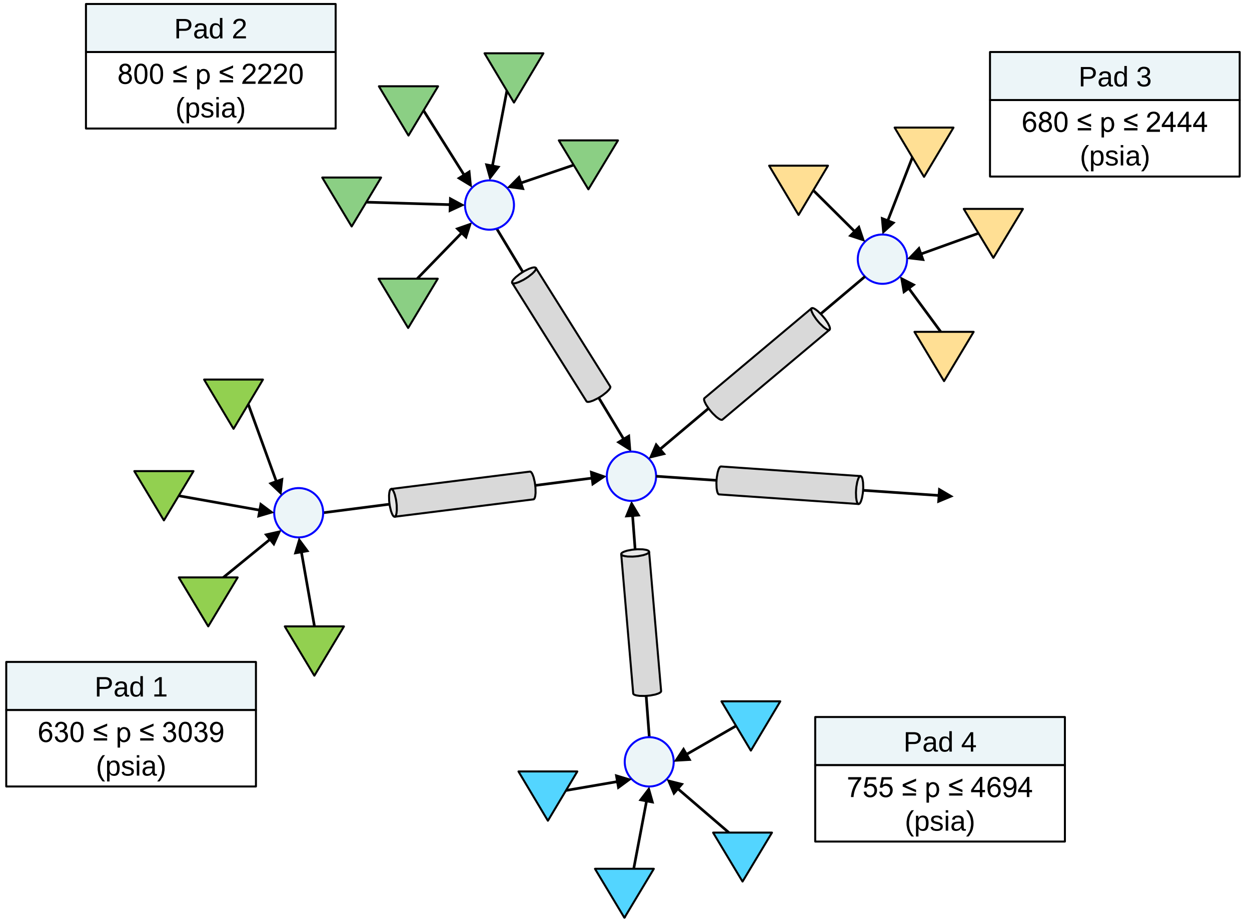
As a first step to solving the optimization problem, we use MATLAB to calculate valid pressure range for each multi-well pad.

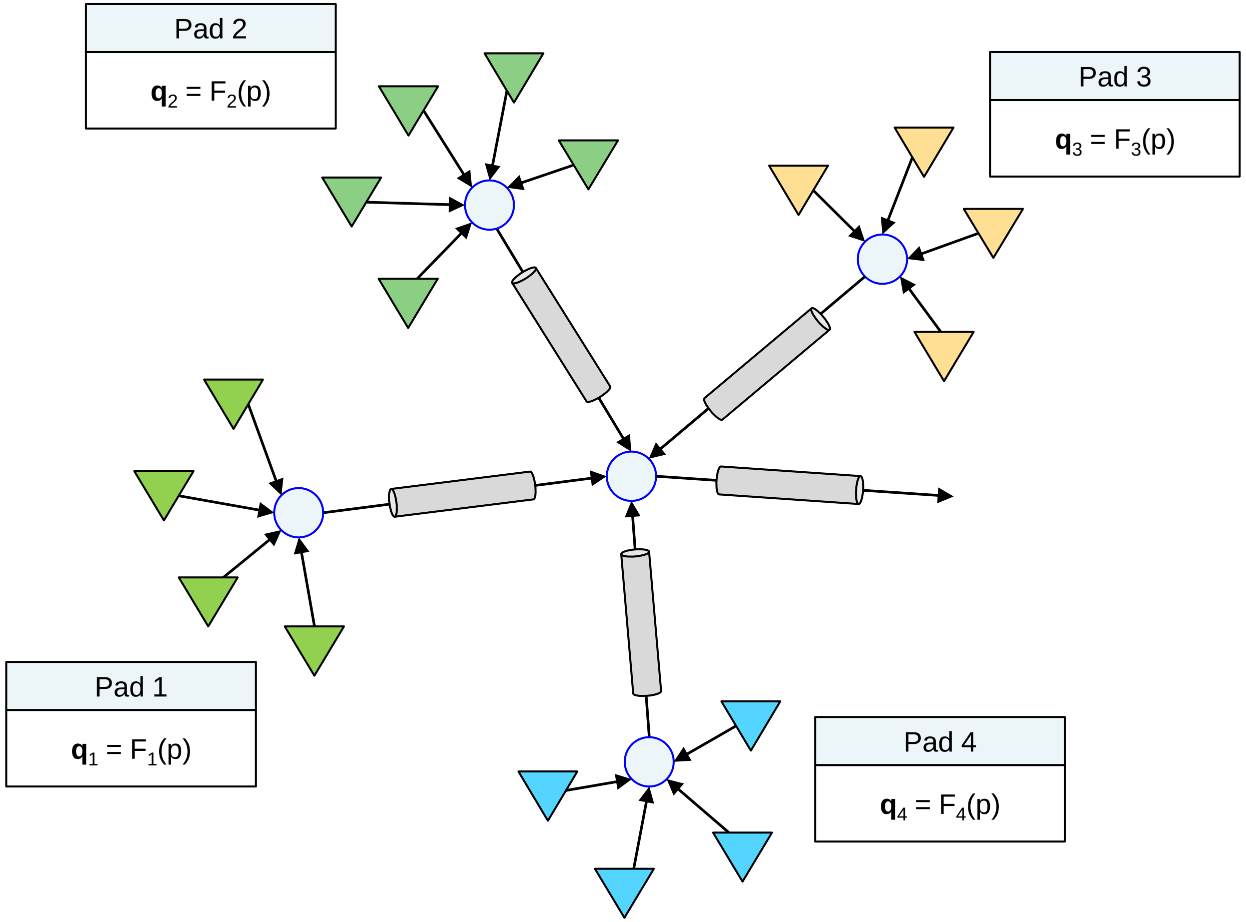




Second, we want to define totalized production rate functions for each multi-well pad using well performance data.

Totalized production

```
function q = computeRates(pads, p)
   % ...
   % Loop through all wells and
   % accumulate flow rates
   % ...
end
```



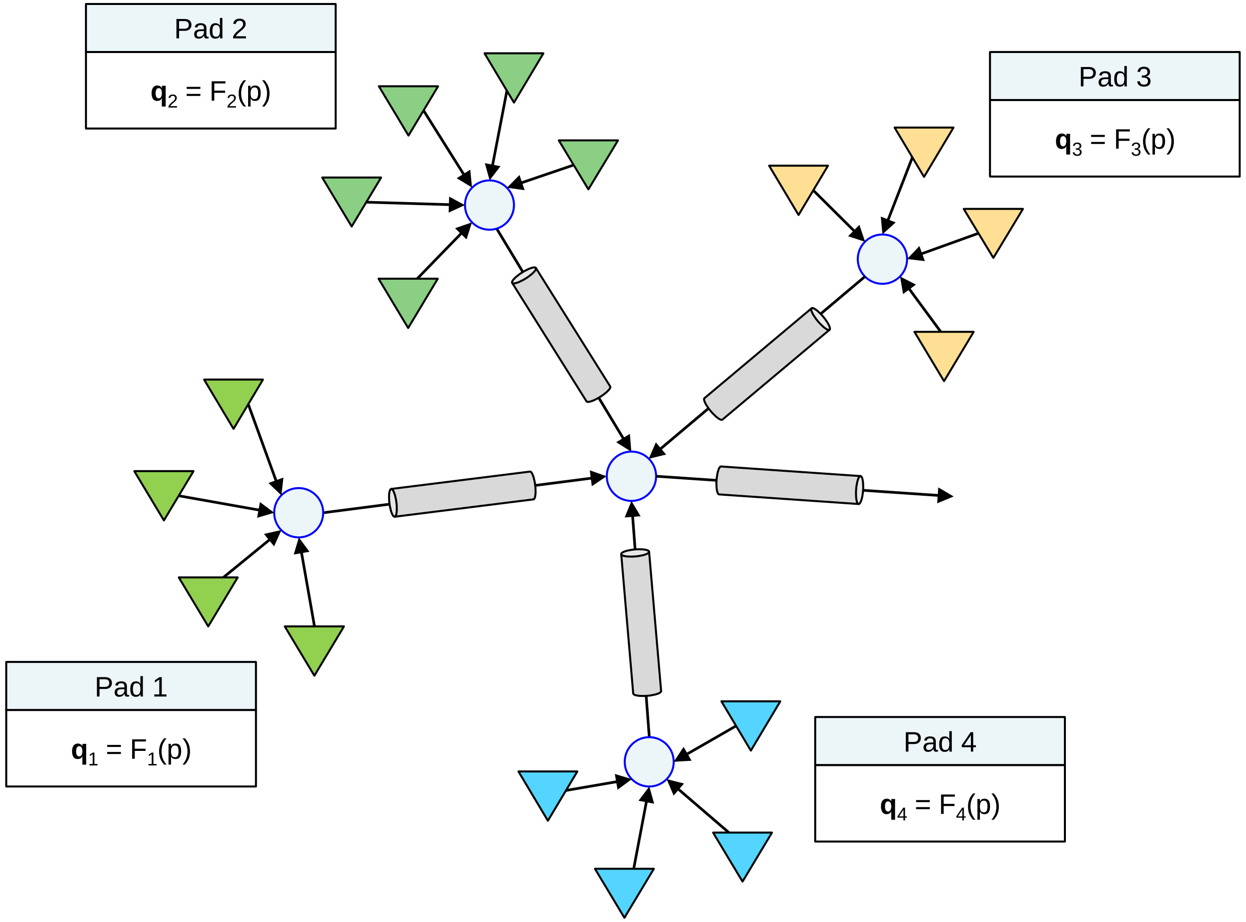
Third, we convert the totalized production function into an optimization expression and define constraints.

Optimization problem set up

```
p = optimvar('p',numPads)

[qo,qg,qw] = fcn2optimexpr(@(p)
    computeRates(pads,p))

prob = optimproblem()
```



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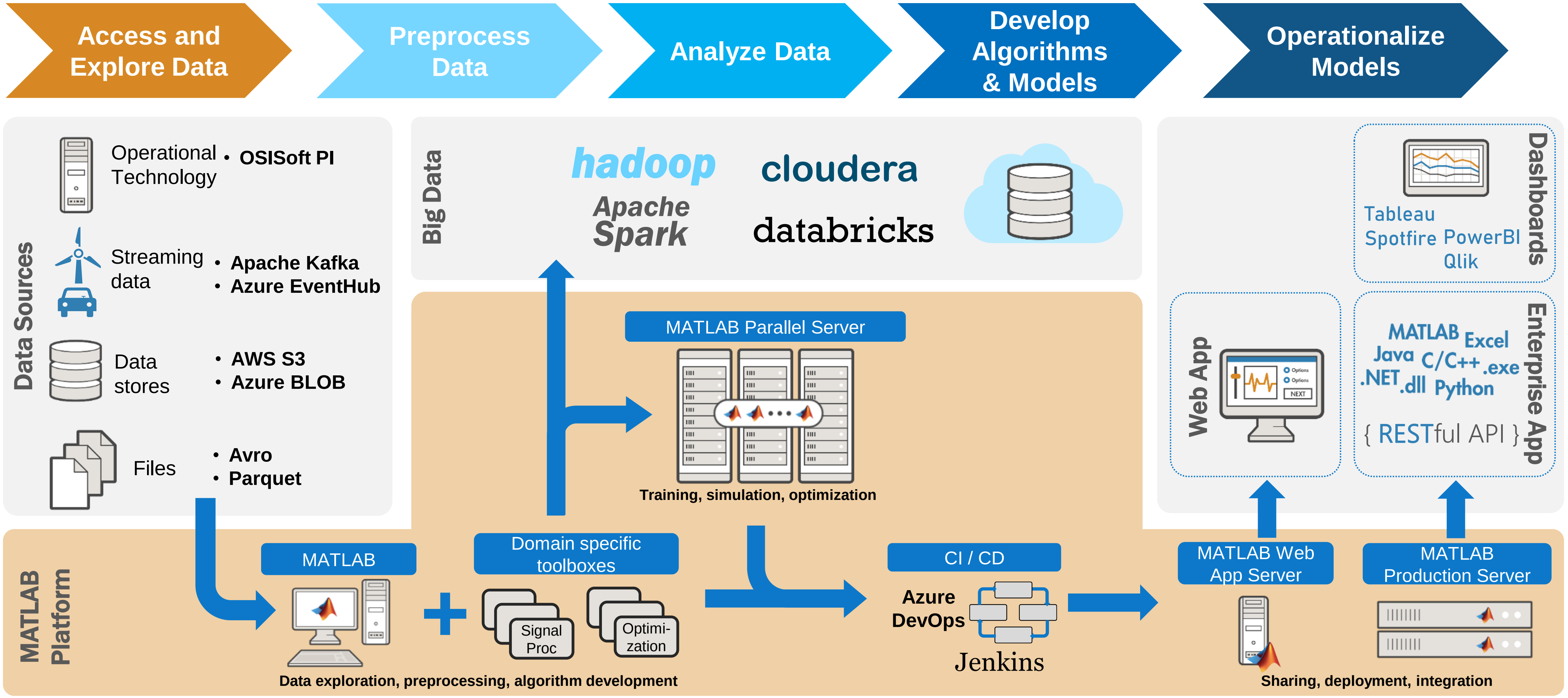
MathWorks provides a comprehensive end-to-end solution for <AI/Data Science/Tech Computing>



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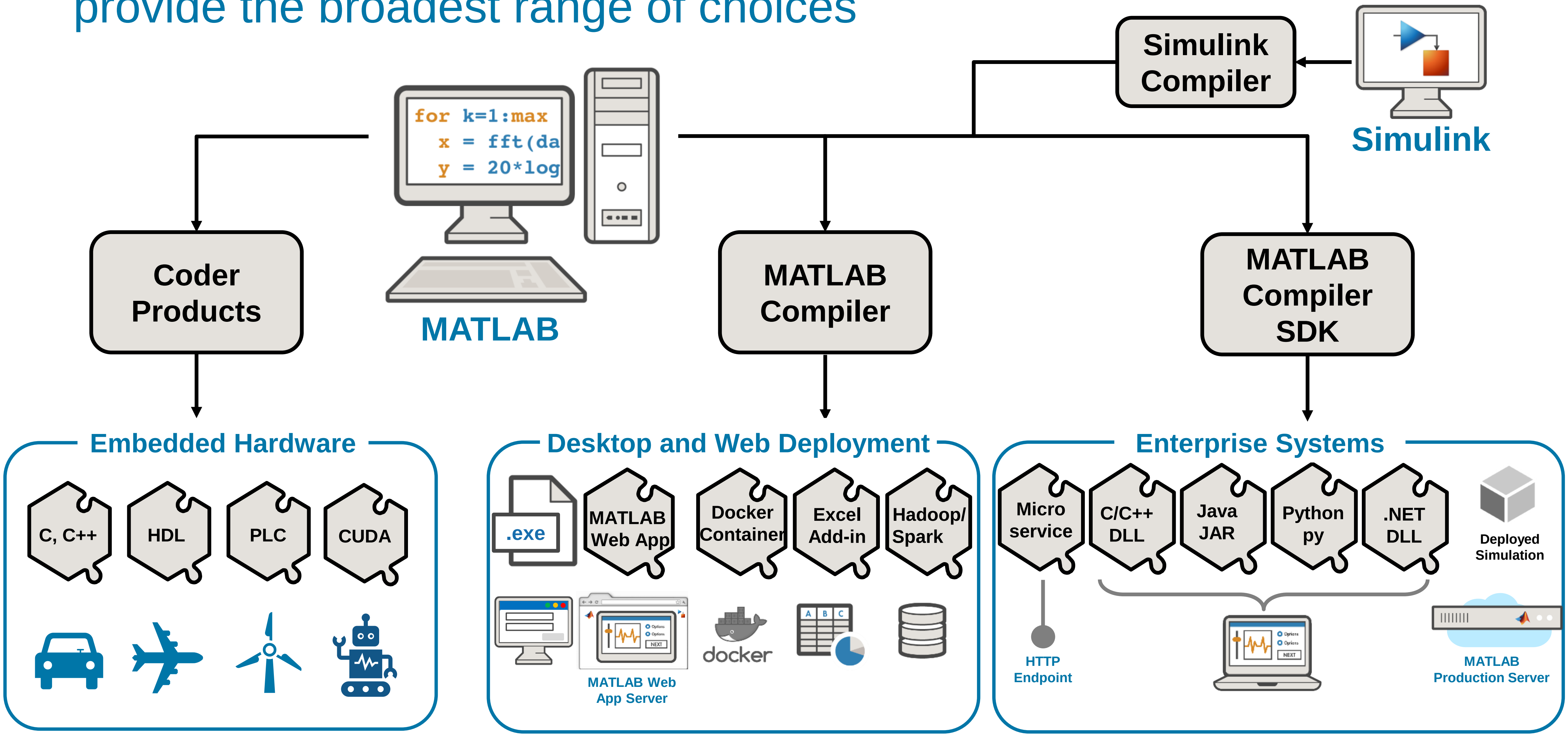
When it comes to operationalizing your <analytics/models> we provide the broadest range of choices



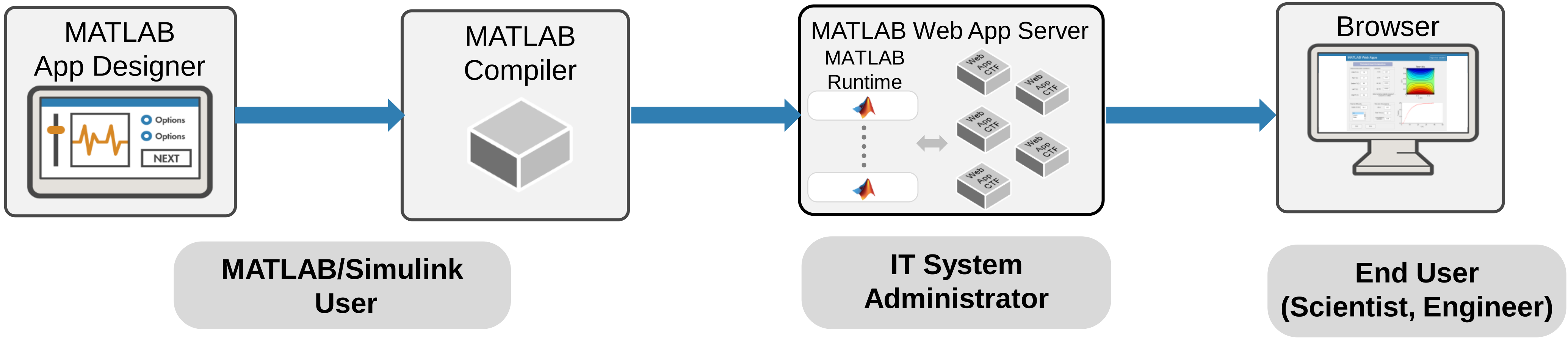
Use MATLAB Web App Server, if you want to easily share MATLAB Web Apps with your colleagues or collaborators

Develop the user interface and callback functions using MATLAB App Designer

Package MATLAB app, data and associated files as MATLAB Web Apps with one click

Deploy MATLAB Web Apps using the upload client directly from the browser

Access and run MATLAB Web Apps directly from a browser



Create MATLAB Web Apps for sharing

- Share your work as MATLAB Web Apps with other engineers and scientists
- Spend more time developing apps than managing distribution

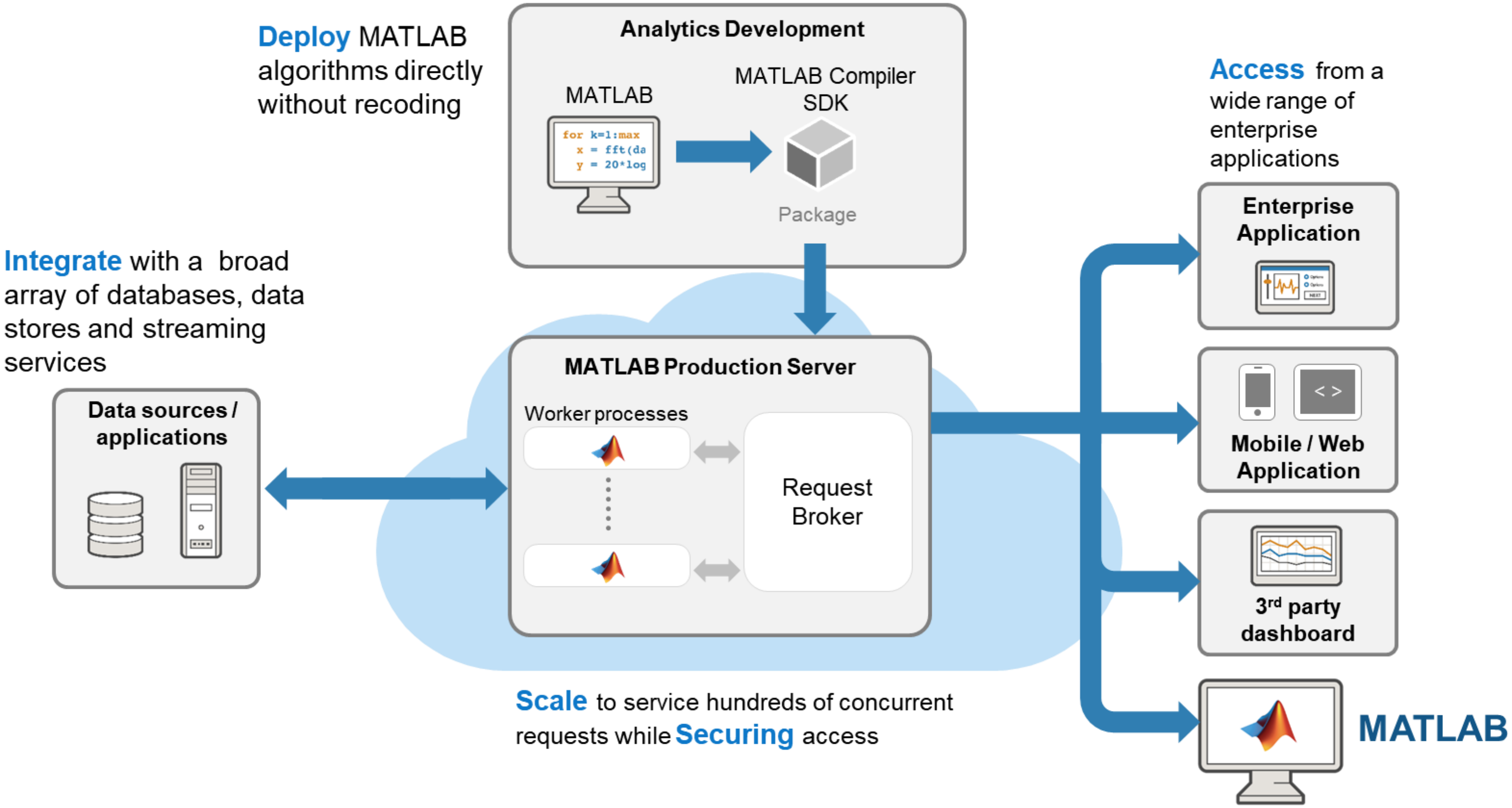
Manage the server infrastructure

- Secure and control access to MATLAB Web Apps
- Save time by eliminating the steps required for application distribution

Easy access to MATLAB Web Apps

- Save time by eliminating the steps to install the application on your desktop
- Access MATLAB Web Apps anywhere using a browser

Use MATLAB Production Server to operationalize your models or algorithms as APIs that are integrated with your enterprise IT/OT systems



Deploy AI / MLOps

- Deploy trained AI models for inference
- Models can be stored in a REDIS in-memory database for high-speed access

Process streaming analytics for IIoT

- Stream data from operational systems through streaming services such as Apache Kafka or Azure EventHub into MATLAB analytics for anomaly detection, condition based monitoring or predictive maintenance

Host Microservices APIs

- Share MATLAB algorithms and functions as microservice APIs in your corporate service fabric

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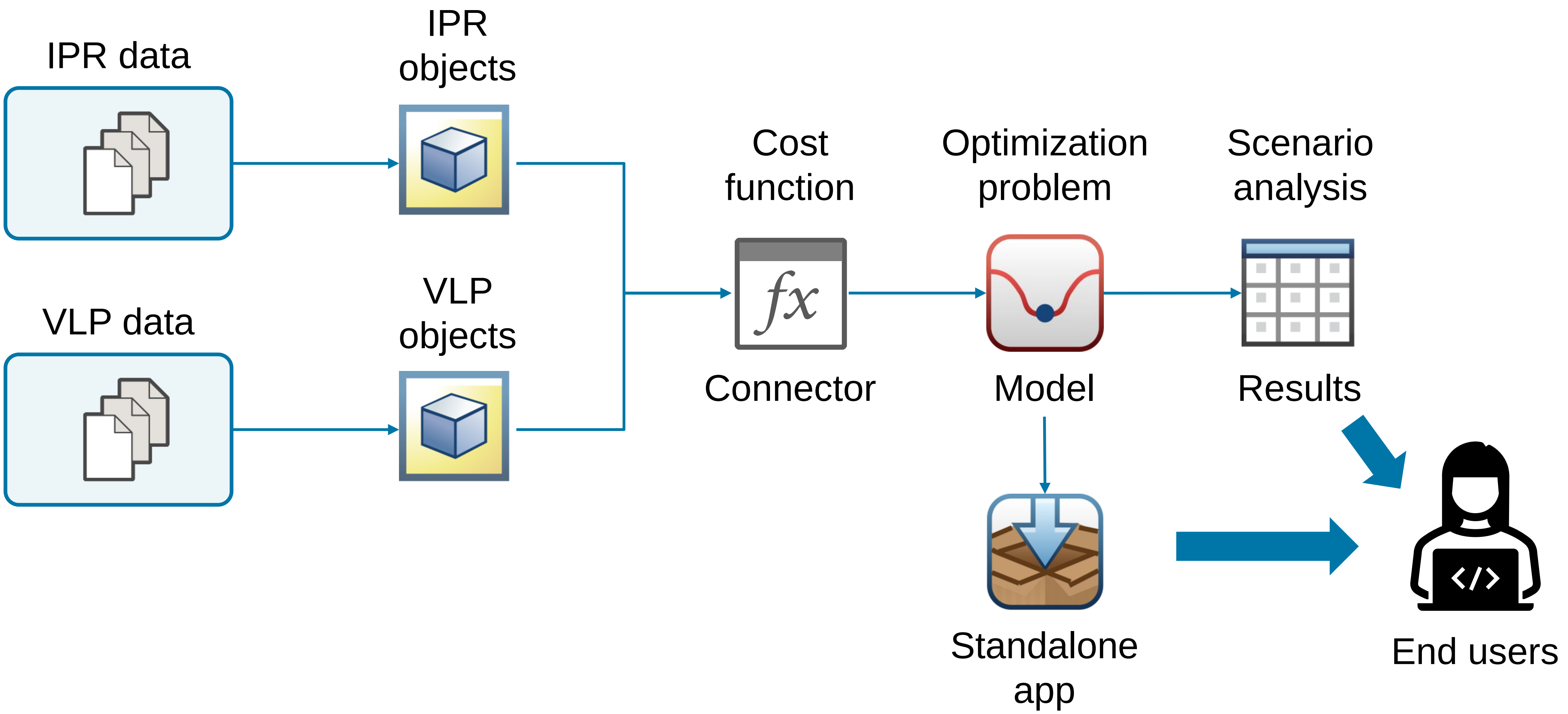
Key Takeaways

- MATLAB helps streamline processing data from external sources
- Optimization Toolbox can tackle very difficult problems with only a few steps
- Users can create and deploy custom optimization workflows as standalone applications (.exe), libraries (Python, Java, .NET, etc.), and microservices.
- MathWorks Training is highly recommended for efficient use of our tools.

MATLAB can tackle very complex optimization problems and create robust, deployable workflows

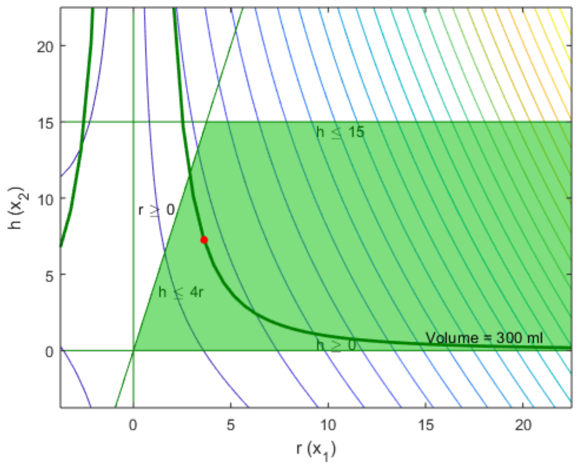


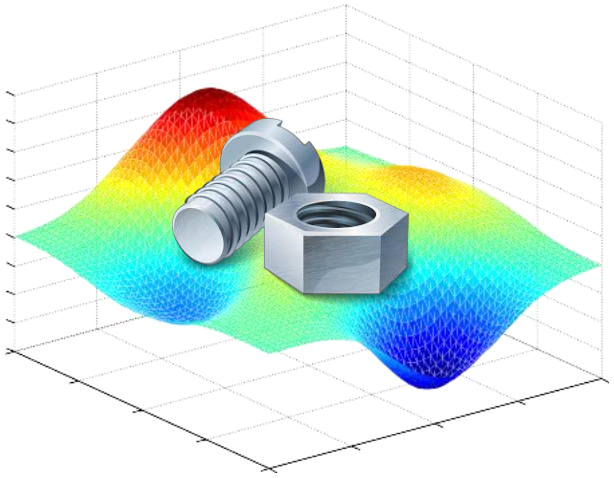
Optimization Techniques in MATLAB

Recommended Training

After this 1-day course you will be able to:

- Run optimization problems in MATLAB
- Specify objective functions and constraints
- Choose solvers and algorithms
- Evaluate results and improving performance
- Use global and multiobjective optimization methods





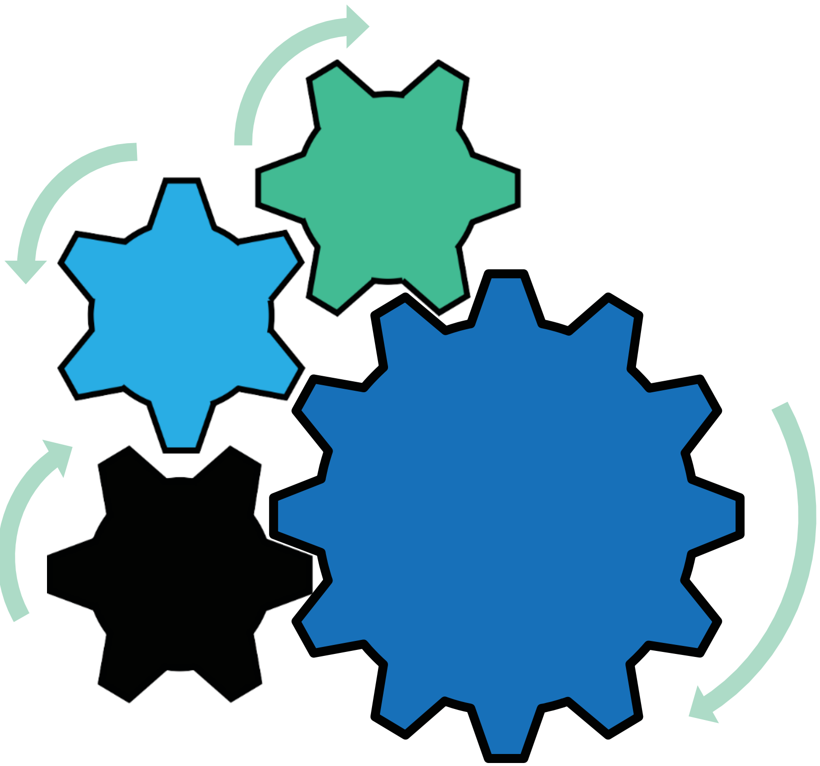
[See detailed course outline]

MATLAB Programming Techniques

Recommended Training

After this 2-day course you will be able to:

- Manage data efficiently
- Utilize development tools
- Structure code
- Create robust applications
- Verify application behavior



[See detailed course outline]