Mathematical Modeling using MATLAB

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Agenda

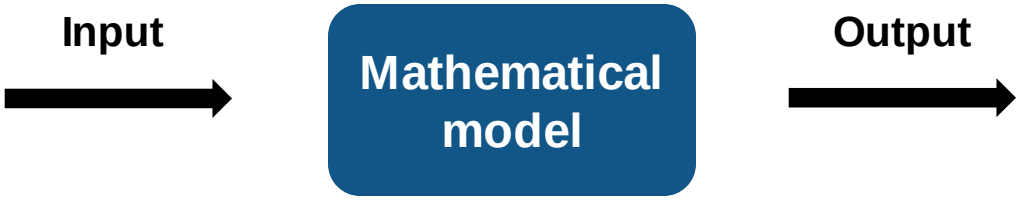
- Challenges in Mathematical Modeling
- Introduction to Mathematical Modeling Techniques
- Mathematical Modeling of a Real World System
  - Deriving and Solving Governing Equations
  - Modeling Systems using Field Data
- MathWorks Services an overview

Challenges

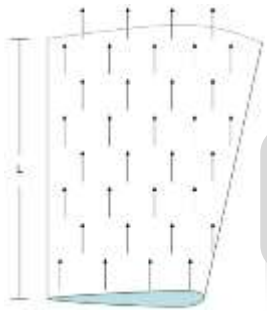
- Getting from mathematical concepts to a software model
- Validation and optimization of the mathematical model against requirements
- Acquiring field data from files, field instruments, and test rigs
- Characterizing systems using field data
- Representing real-world datasets as optimized lookup tables
- Utilizing the power of multiple processing cores to speed up calculations
- Deploying models across a whole organization

What is mathematical modeling?

- Use of mathematical language to describe a system or process

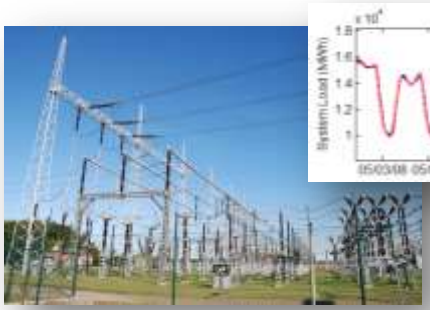


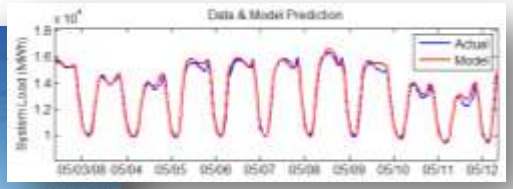
- Some simple examples



$$q_l = \frac{2W_{to} n \sqrt{L^2 - x^2}}{L^2 \pi}$$

Lift on aircraft wing



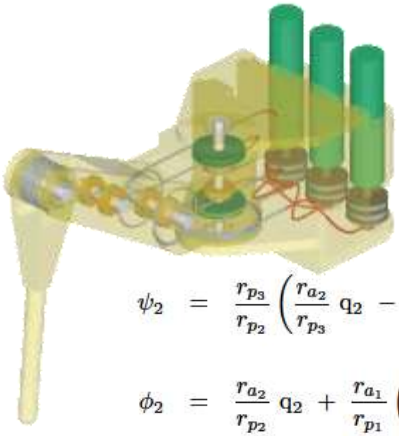


$$EL = f(T, t, DP, \ldots)$$

Electricity load

Why develop mathematical models?

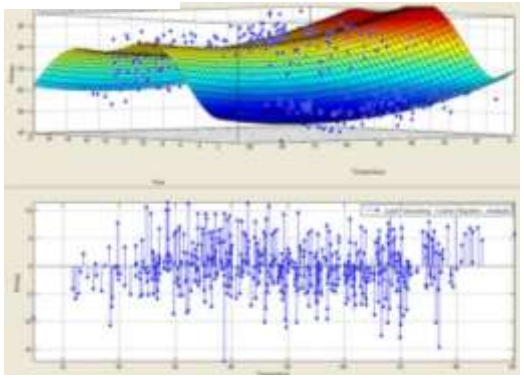
- ***Forecast system behavior***
  Predict and gain insight into system behavior for various "what-if" scenarios
  - Enables critical decisions
  - Reduces the need for testing



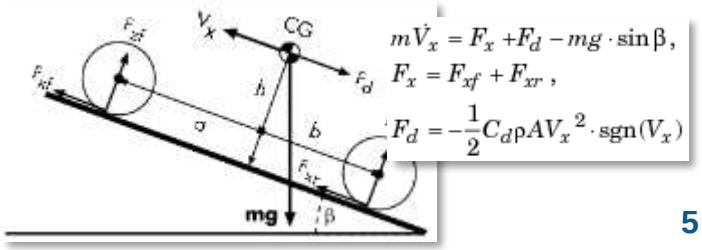
$$\psi_2 = \frac{r_{p_3}}{r_{p_2}}\left(\frac{r_{a_2}}{r_{p_3}}\,q_2 - \frac{r_{a_1}}{r_{p_1}}\,q_1\right)$$

$$\phi_2 = \frac{r_{a_2}}{r_{p_2}}\,q_2 + \frac{r_{a_1}}{r_{p_1}}\left(\frac{r_{p_2} - r_{p_3}}{r_{p_2}}\right)q_1$$

- ***Optimize system behavior***
  Identify parameters that optimize system performance

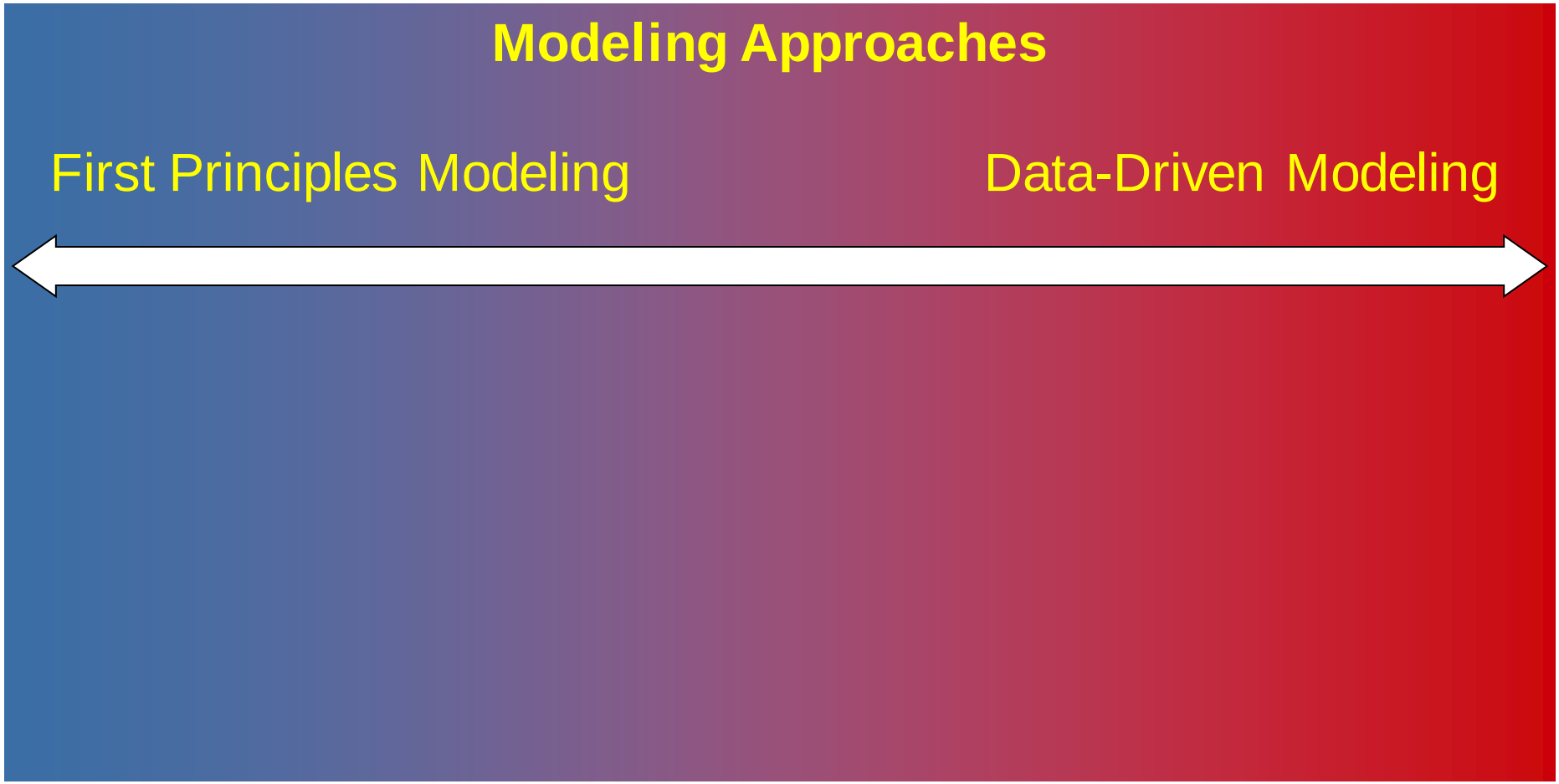


- ***Design control systems***
  Develop model to represent plant during control system design

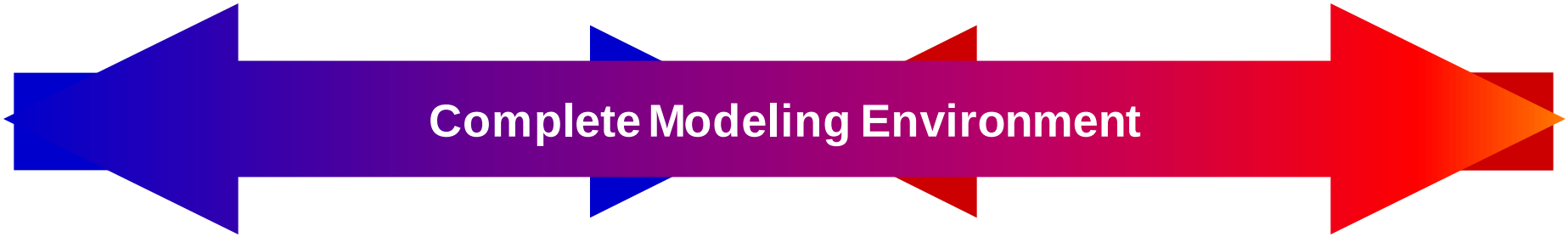


$$m\dot{V}_x = F_x + F_d - mg\cdot\sin\beta,$$
$$F_x = F_{xf} + F_{xr},$$
$$F_d = -\frac{1}{2}C_d\rho A{V_x}^2\cdot\mathrm{sgn}(V_x)$$

Different Modeling Approaches



Both have advantages & disadvantages



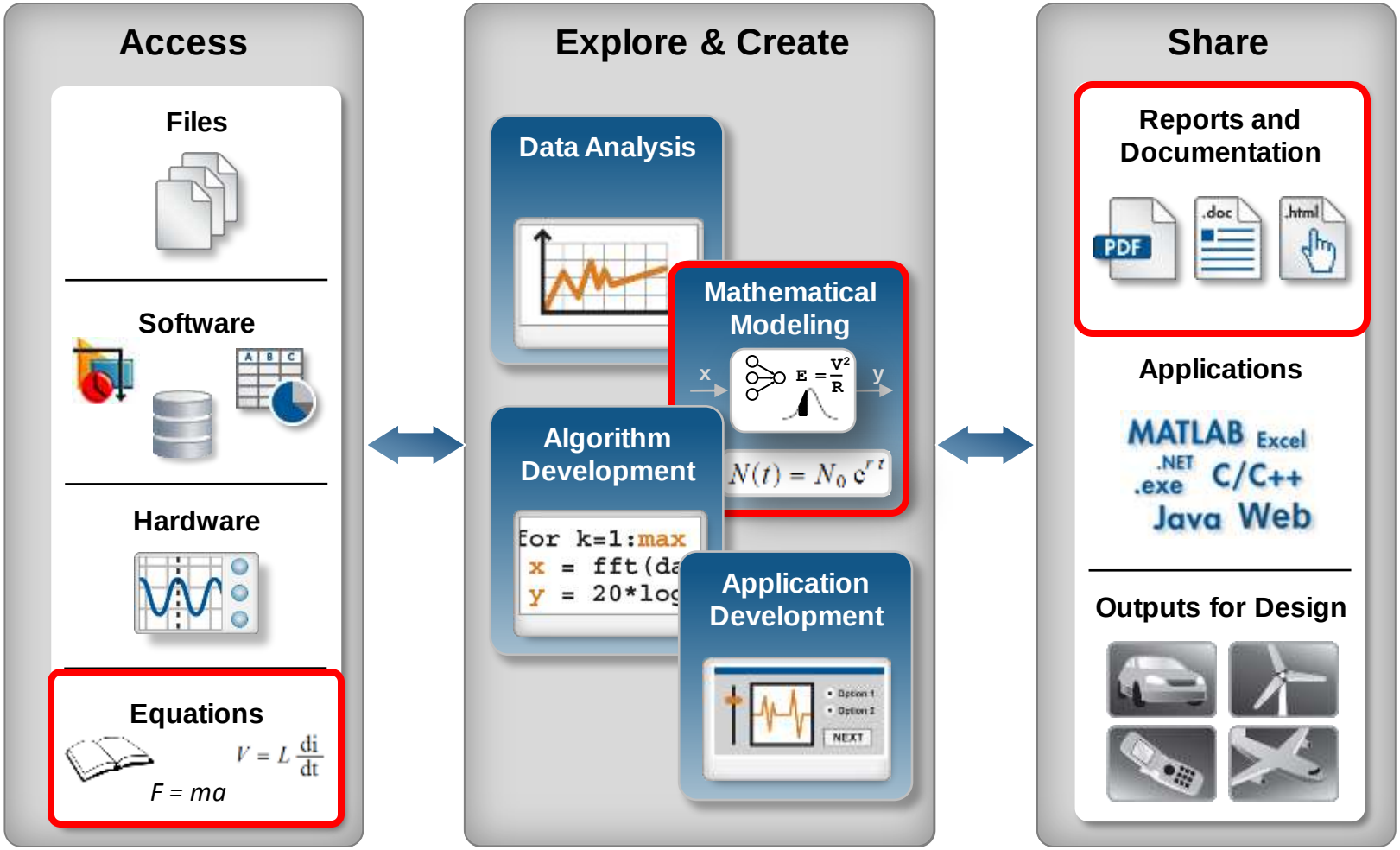
Advantages:
- Fast
- Accurate

Disadvantages:
- Requires plant
- Requires data acquisition system

Advantages:
- Insight in behavior
- Physical parameters

Disadvantages:
- Time-consuming
- Requires expertise

Modeling with Governing Equations (or) First Principles Modeling



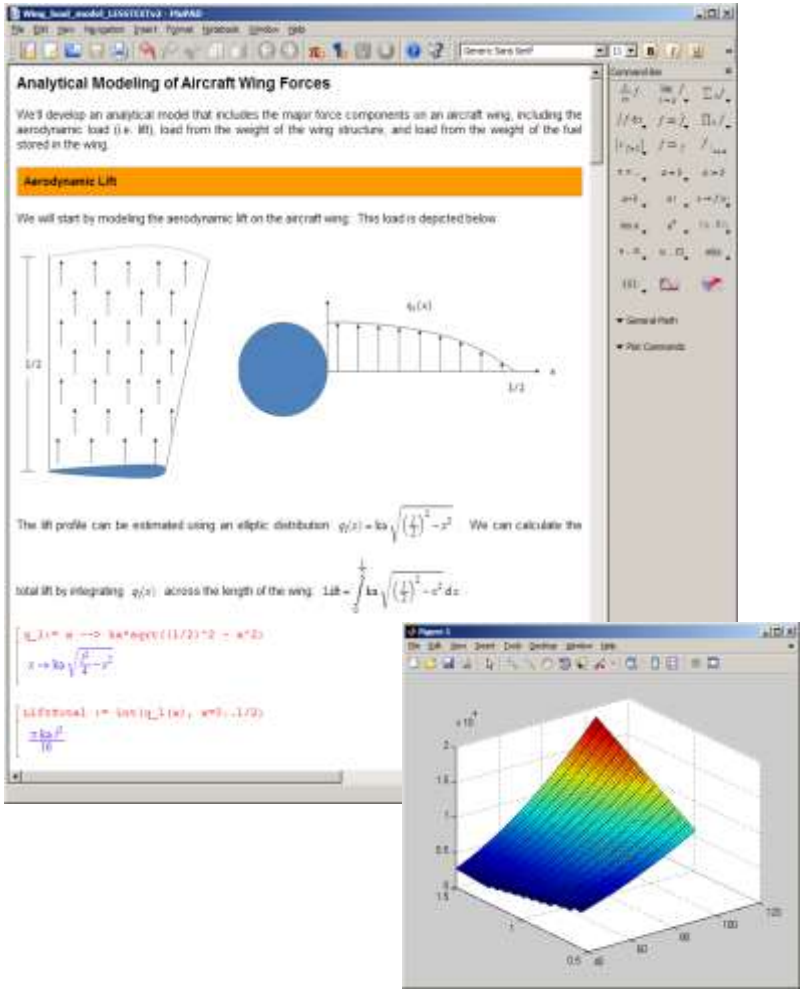
Demo: Modeling aircraft wing loads

Problem:

- Determine whether bending moments on aircraft wing are within design limit

Workflow:

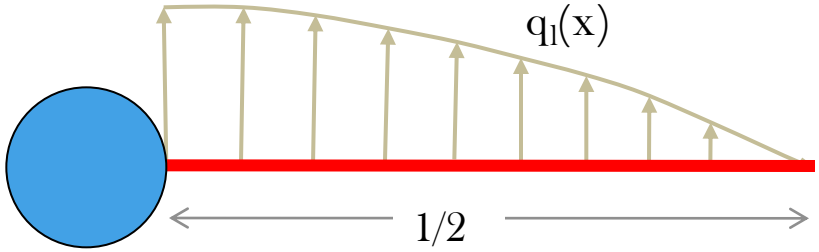
- Derive analytical models for wing loads and bending moment
- Simulate bending moment for different "what if" scenarios
- Analyze simulation results to determine whether worst-case bending moments are within design limit



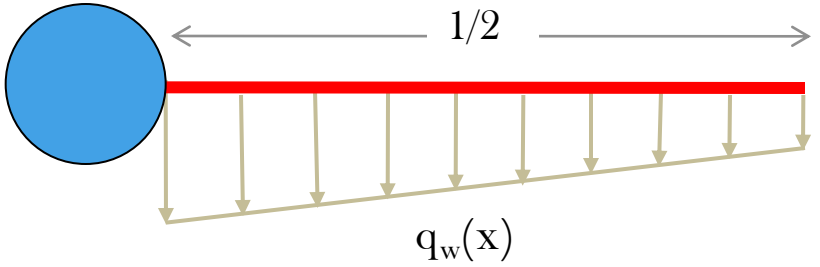
Demonstration:

Analytical Modeling of Aircraft wing forces

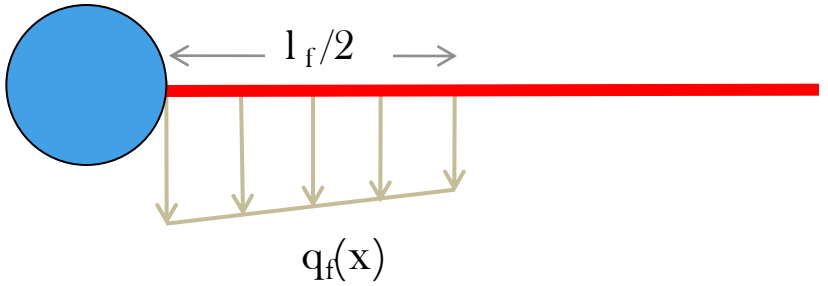
Load 1: Aerodynamic lift



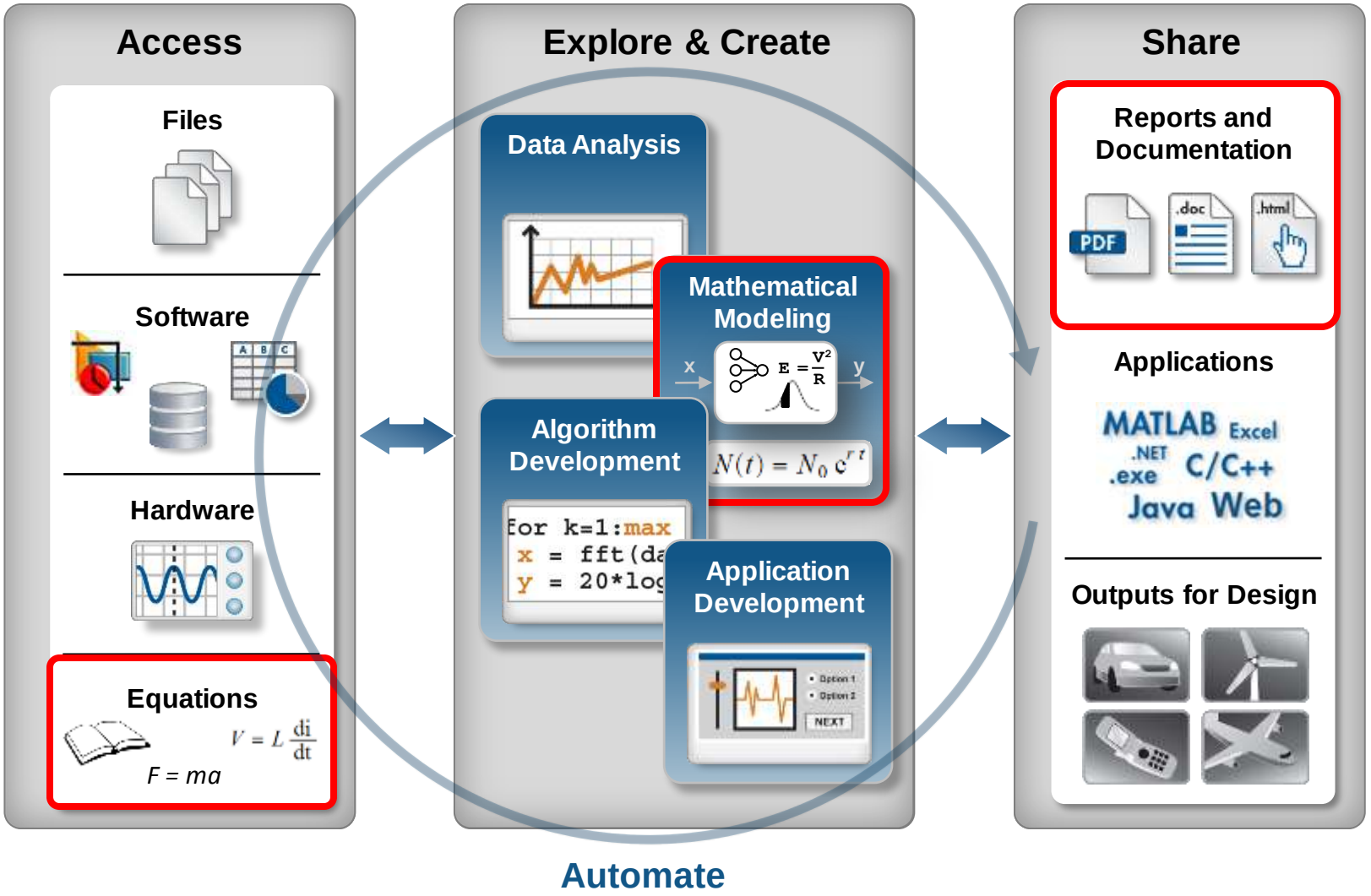
Load 2: Structural load



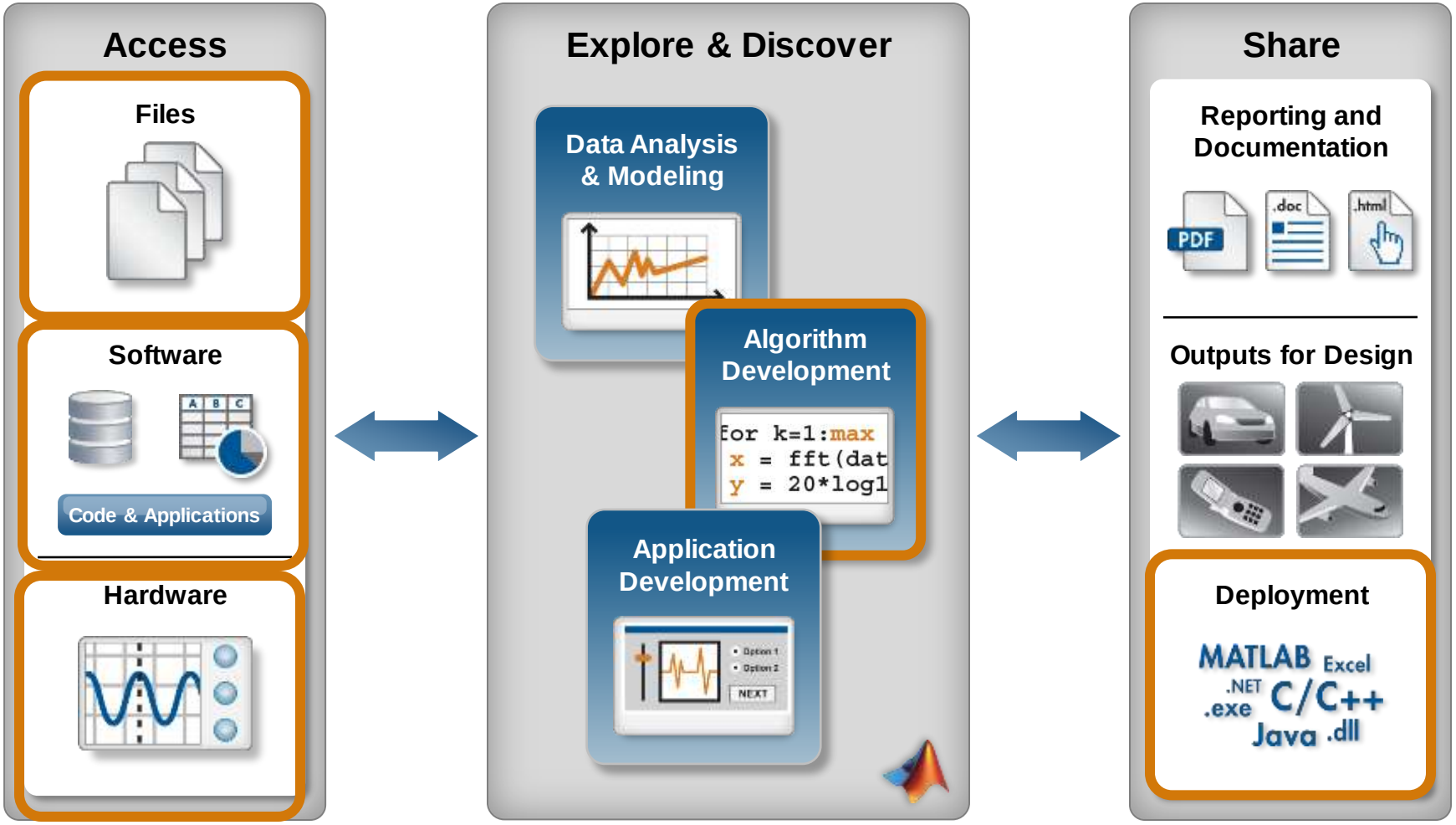
Load 3: Fuel Load



Modeling with Governing Equations (or) First Principles Modeling

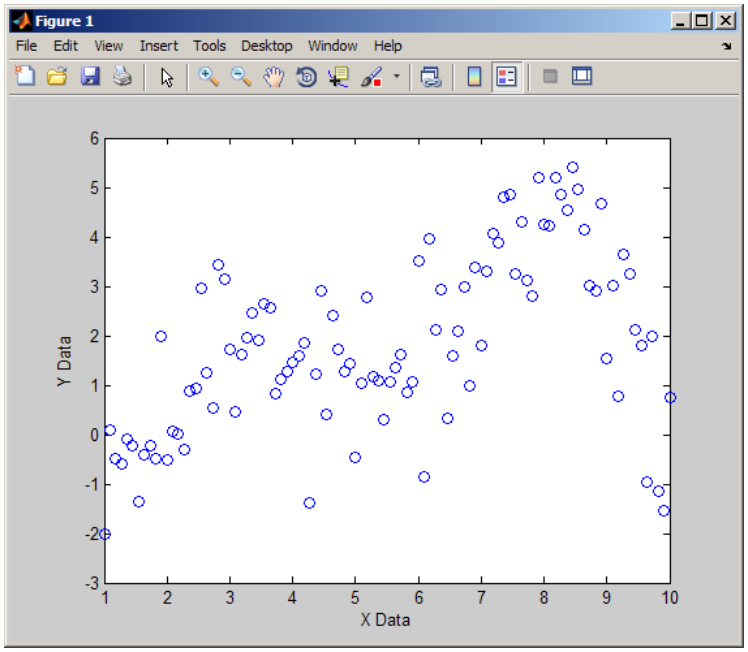


Data Driven Modeling Workflow

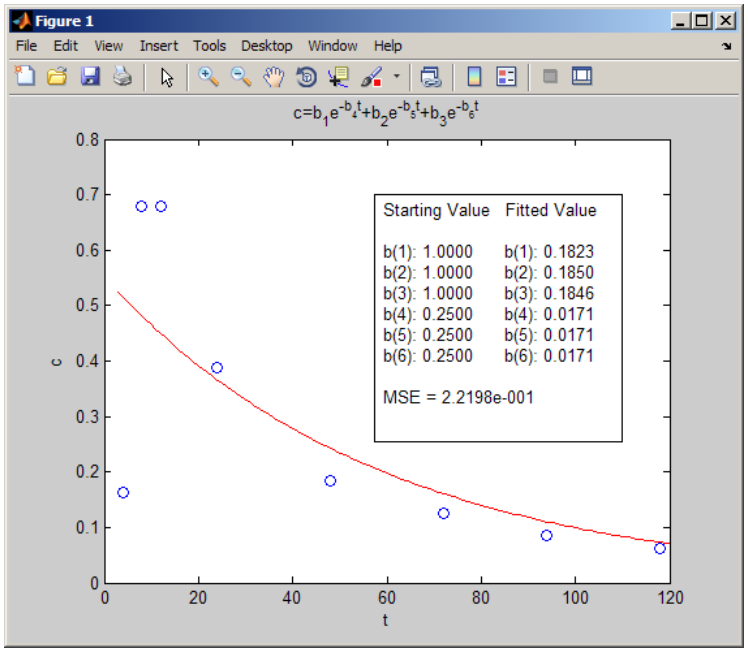


Data Driven Modeling Using Statistical Methods

- Two common challenges in creating an accurate curve fit



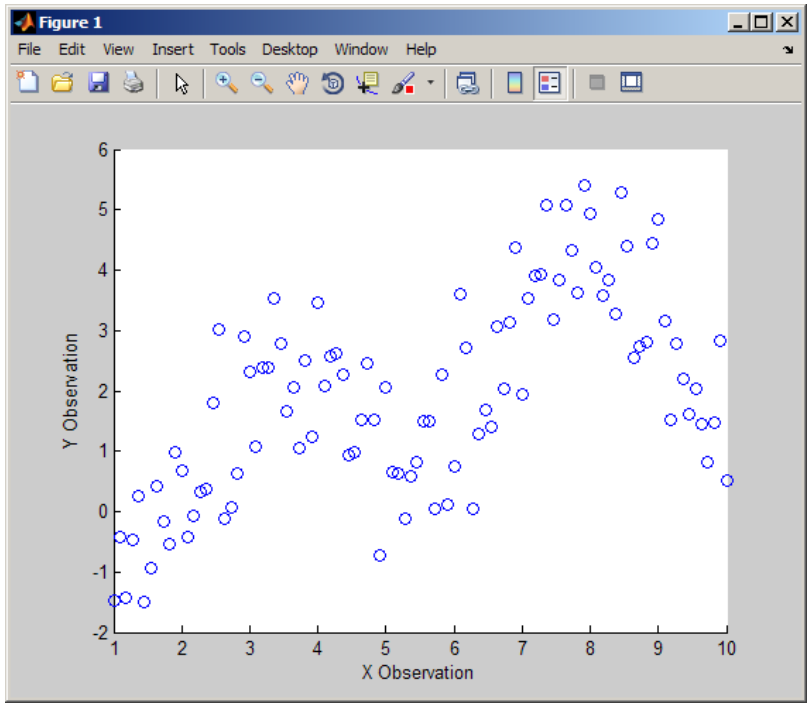
Can't describe the relationship between your variables



Can't specify good starting points for your solvers

Challenge 1

Generating a Good Fit Without Domain Knowledge



Regression Techniques

- Require that the user specify a model
- Choice of model is based on domain knowledge

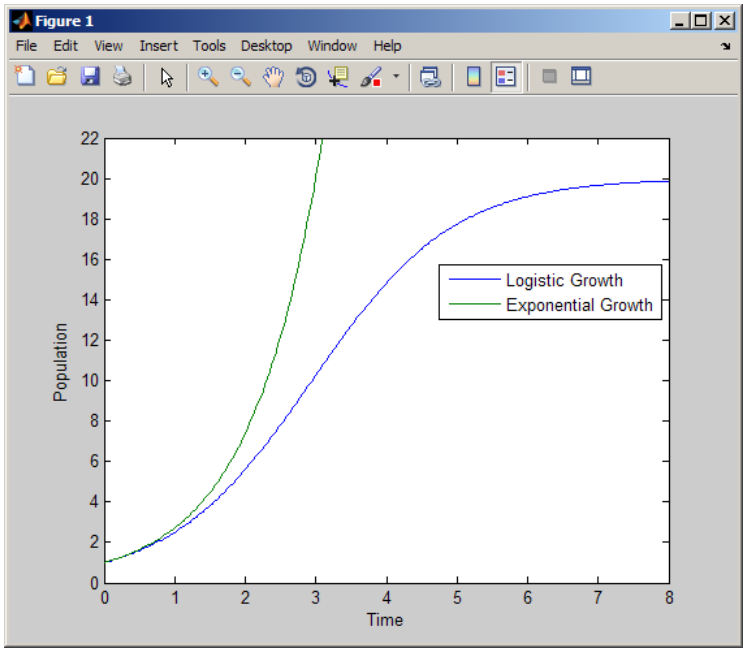
Example - Population models

Logistic Growth

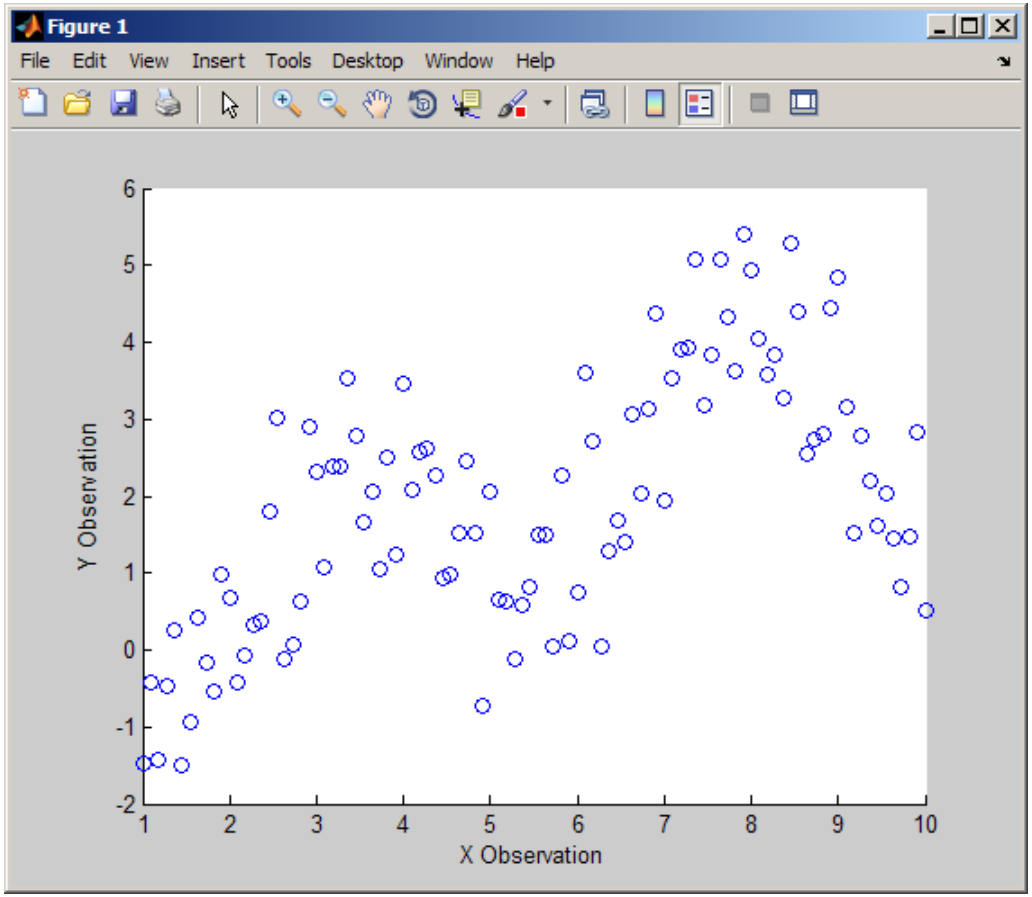
$$N_t = \frac{N_0 \times K}{N_0 + (K - N_0) \times \exp(-r_0 \times t)}$$

Exponential Growth

$$N_t = N_0 \times e^{(r \times t)}$$

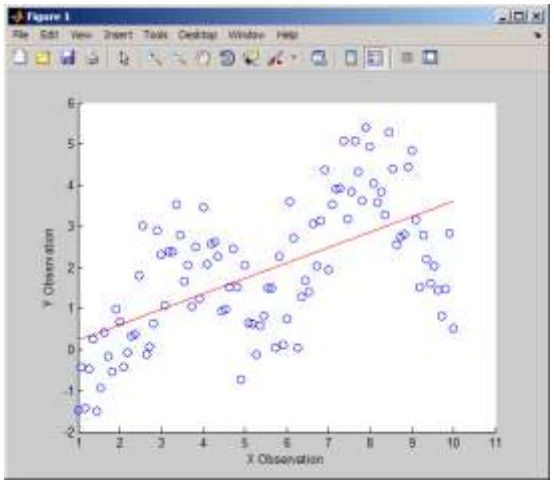


What if you don't know what type of model to use?

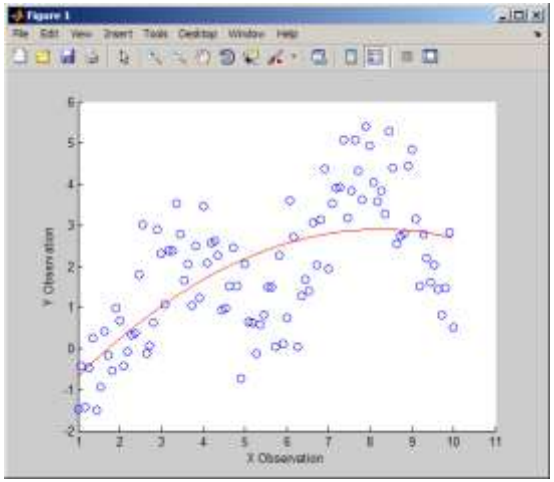


What if you don't know what type of model to use?

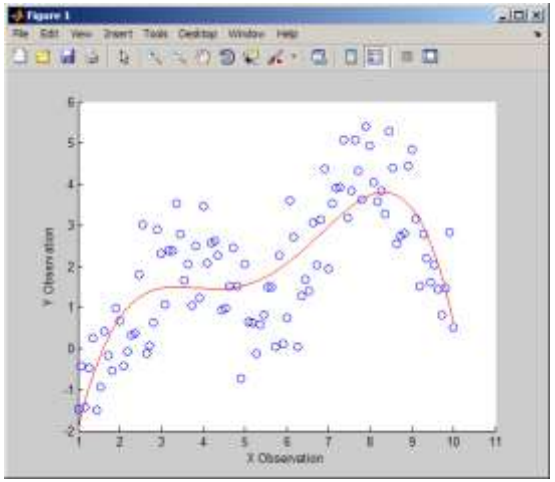
Line ???



Quadratic ???



Rational ???

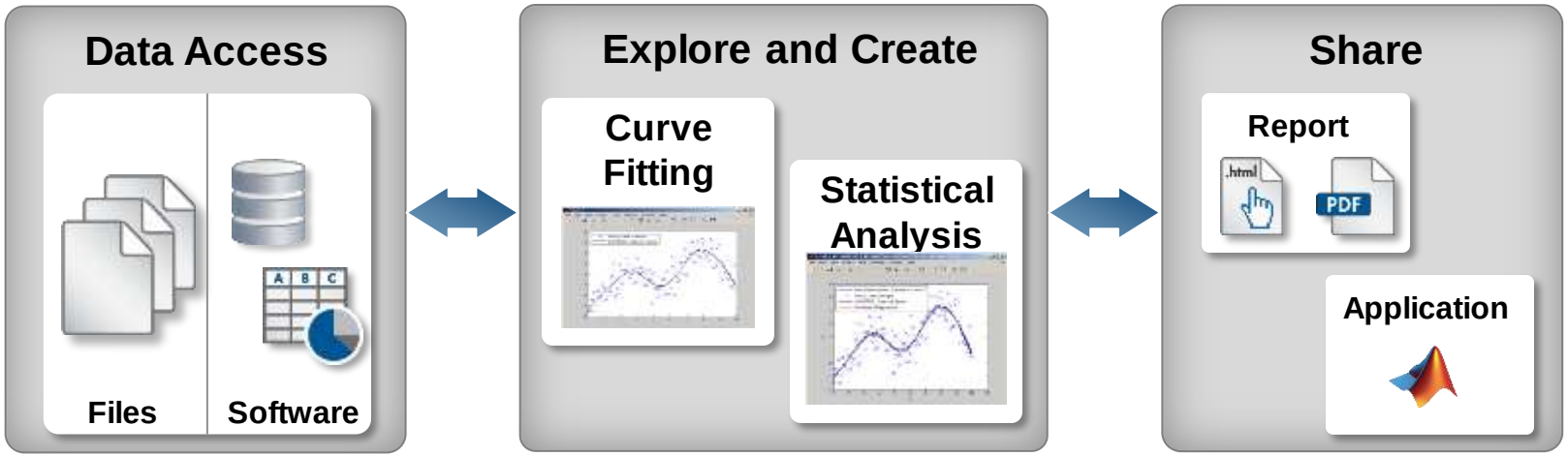


Workflow – Non-Parametric Fitting

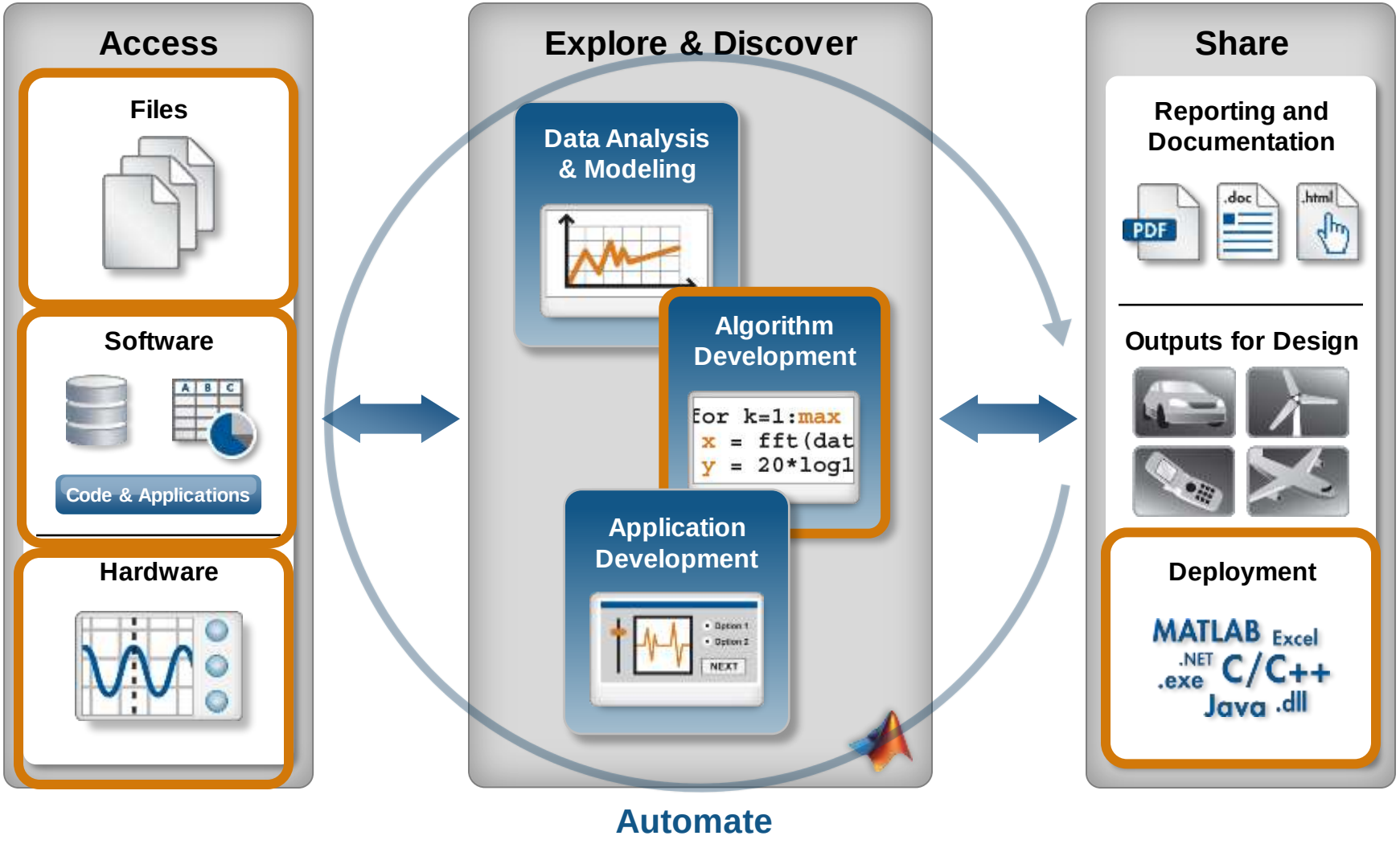
- Get the data to fit, into MATLAB

- Perform non-parametric curve fitting
- Cross validate using statistical methods
- Compare results

- Automatic publish
- Share MATLAB files



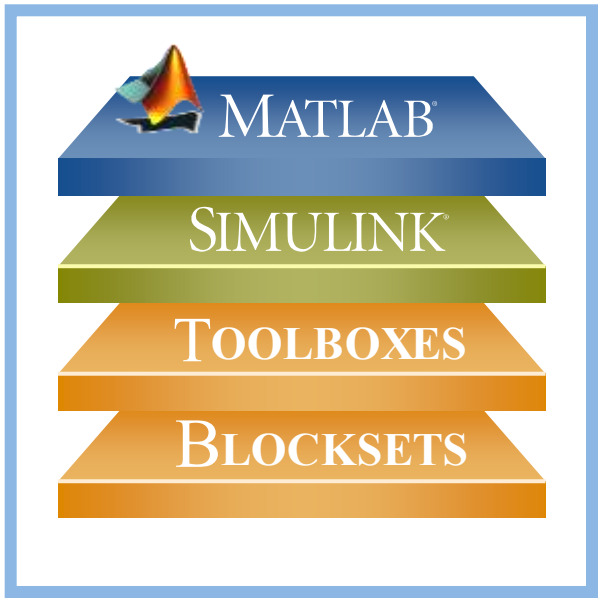
Data Driven Modeling Workflow

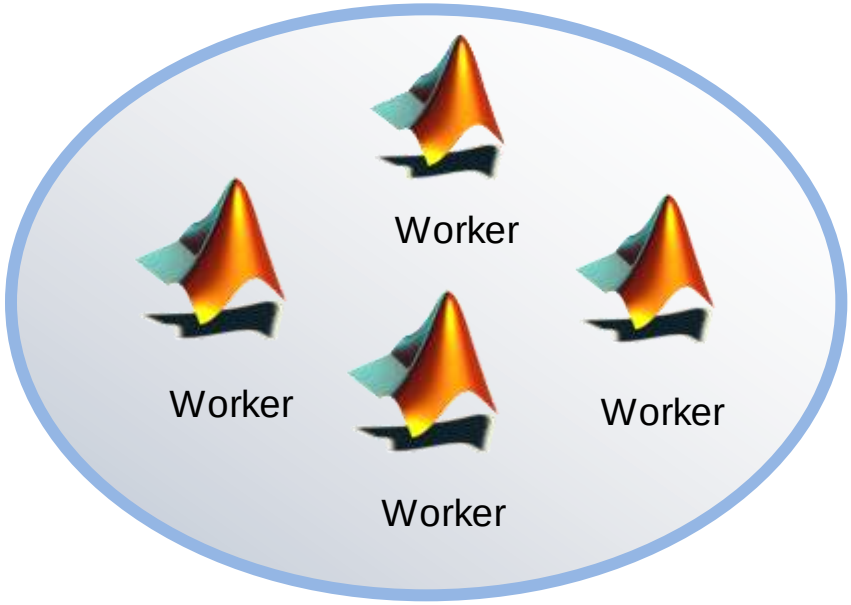


Solving Big Problems

Problem	You could…	Solutions
Long running Computationally intensive	Wait	 Run similar *tasks* on independent processors in *parallel*
Large data set	Reduce size of problem	 Load *data* onto multiple machines that work together in *parallel*

Task Parallel Applications





Parallel Computing enables you to …

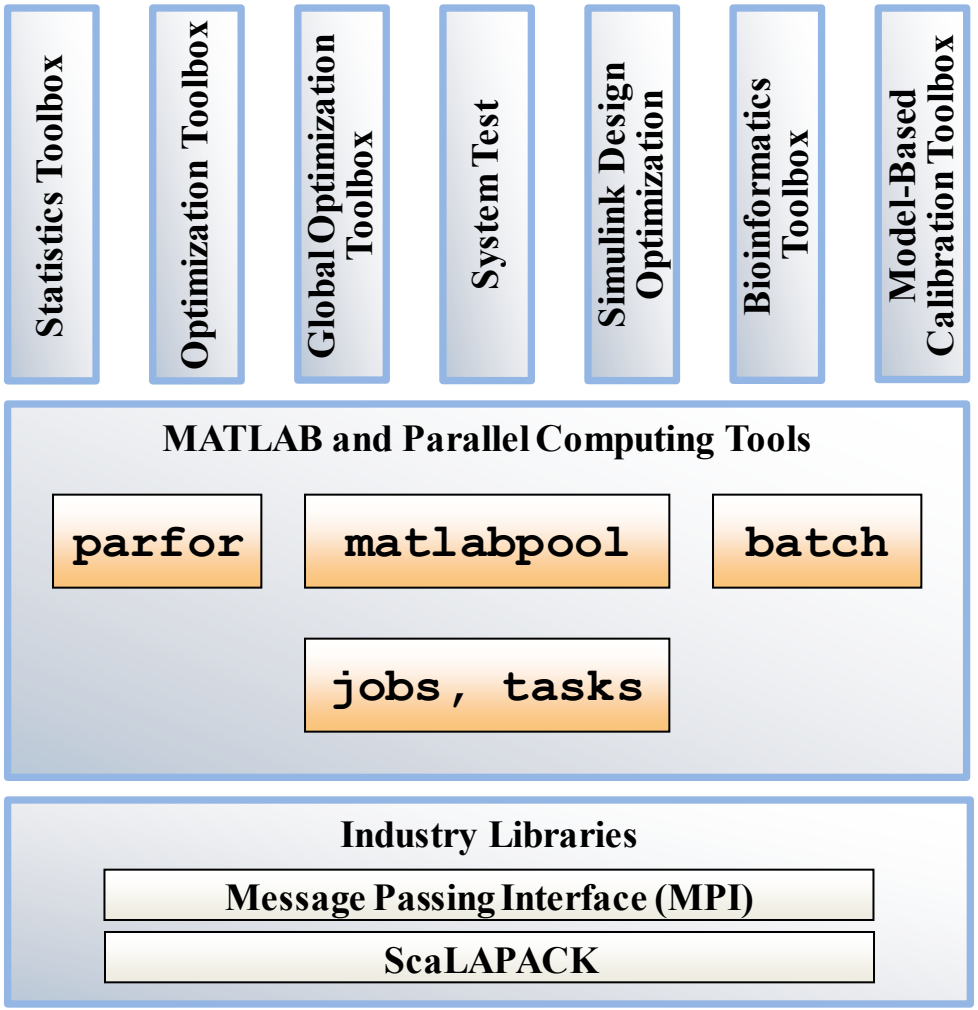
Speed Up Computations

Task 1 | Task 2 | Task 3 | Task 4

Work with Large Data

Parallel Computing with MATLAB

- Built in parallel functionality within specific toolboxes (also requires Parallel Computing Toolbox)
- High level parallel functions
- Low level parallel functions
- Built on industry standard libraries



Writing Parallel Code

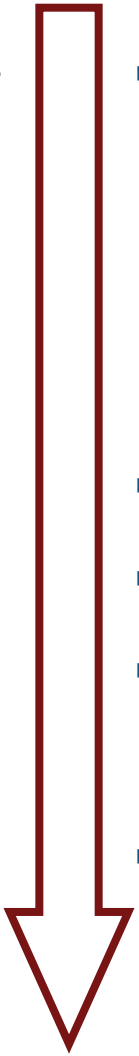
No code changes

- Other toolboxes:
  - Optimization Toolbox™
  - Genetic Algorithm and Direct Search Toolbox™
  - SystemTest™

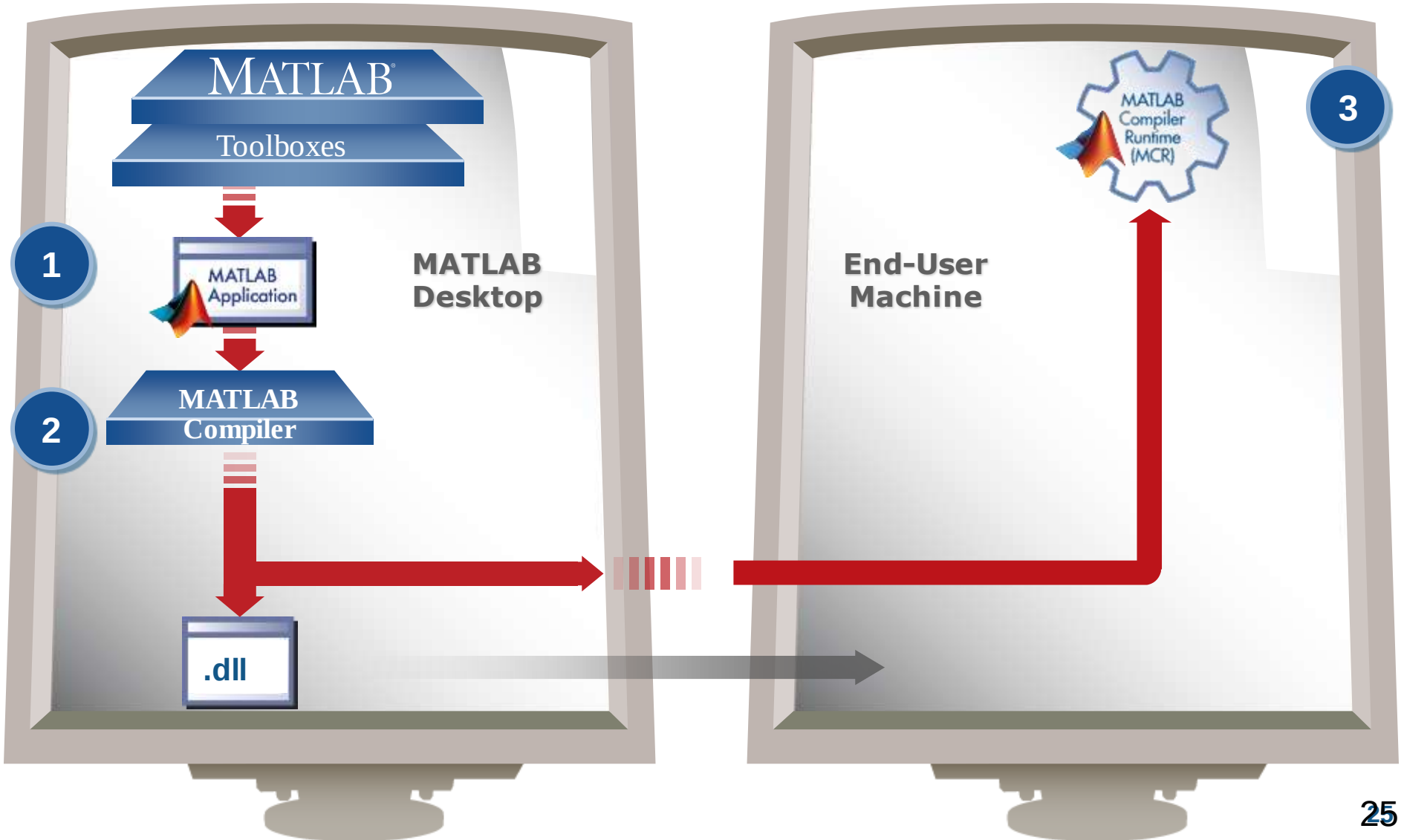
Trivial changes

- parfor
- distributed arrays
- jobs and tasks

- MATLAB MPI

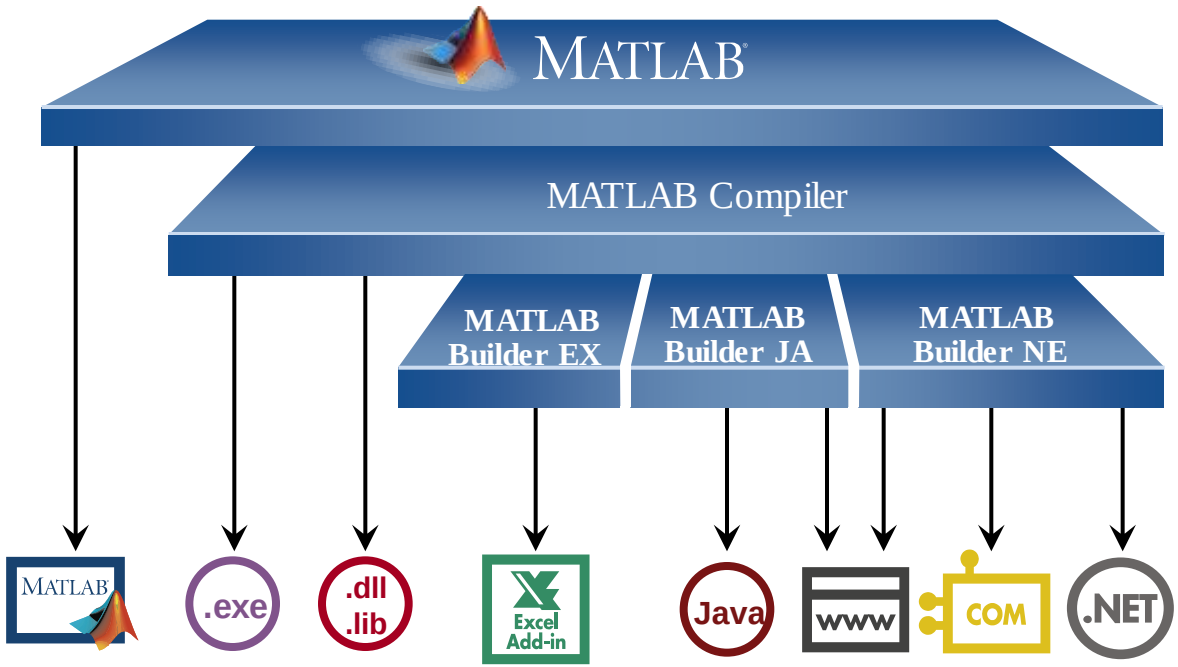


Deploying MATLAB Models



Deploying Applications with MATLAB

- Give MATLAB code to other users
- Share applications with end users who do not have MATLAB
  - Use MATLAB Compiler to create standalone executables and shared libraries
  - Use MATLAB Compiler add-ons to create software components



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Public Trainings in the next Few Months

Course	Dates	Location
Simulink for System and Algorithm Modeling	20 Aug 2012 – 21 Aug 2012	Bangalore
Embedded Coder for Production Code Generation	22 Aug 2012 – 24 Aug 2012	Bangalore
MATLAB Fundamentals	03 Sep 2012 – 05 Sep 2012	Bangalore
MATLAB Programming Techniques	06 Sep 2012 – 07 Sep 2012	Bangalore
MATLAB Fundamentals	24 Sep 2012 – 26 Sep 2012	Pune
Simulink for System and Algorithm Modeling	27 Sep 2012 – 28 Sep 2012	Pune
Statistical Methods in MATLAB	15 Oct 2012 – 16 Oct 2012	Bangalore
MATLAB Based Optimization Techniques	17 Oct 2012	Bangalore
Stateflow for Logic-Driven System Modeling	18 Oct 2012 – 19 Oct 2012	Bangalore

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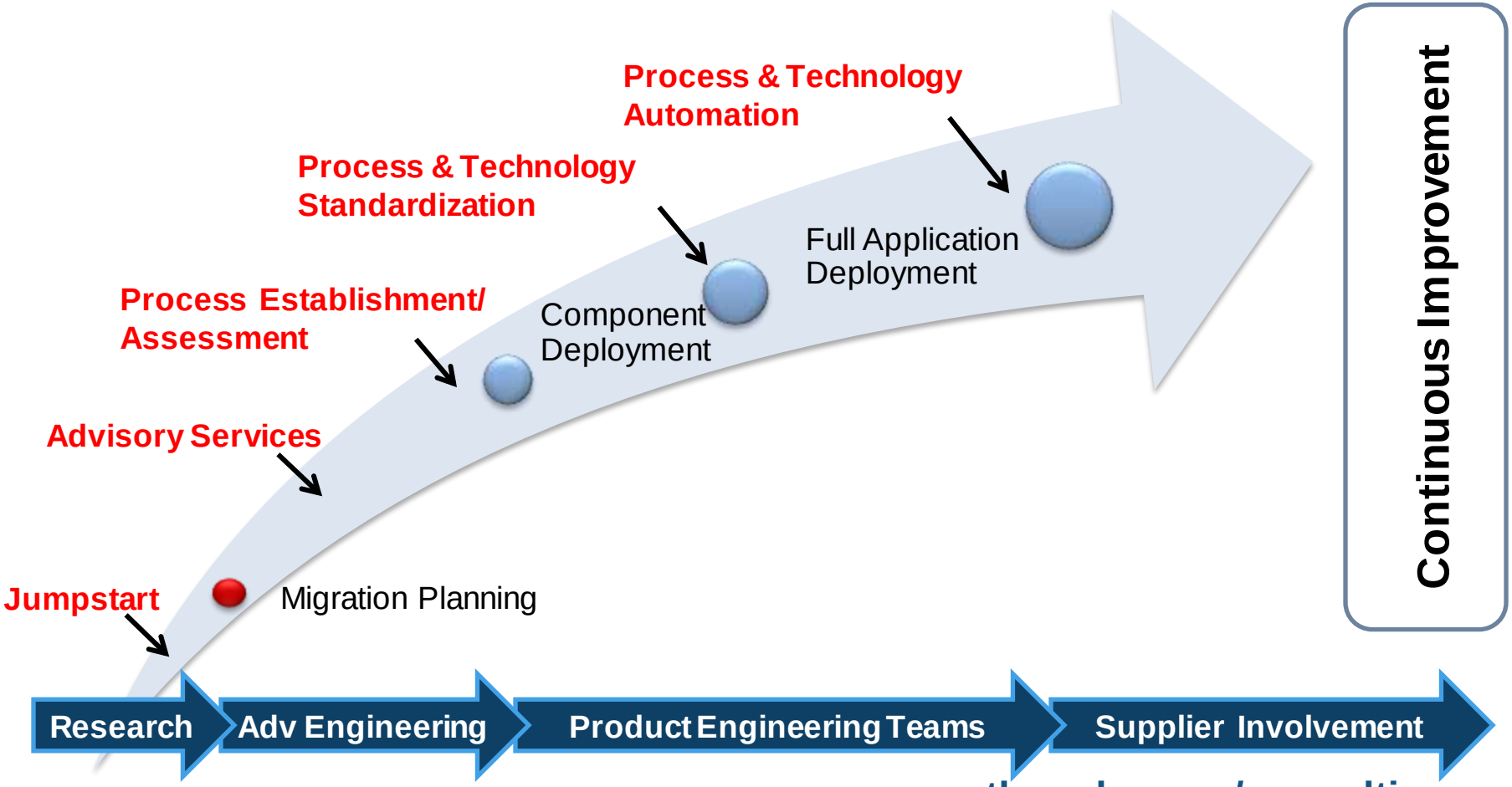
Consulting Services

A global team of experts provide support from initial project startup through integrated process automation to increase productivity and maximize the value of product investments



MATLAB for Quantitative Tools to Manage Risk

Challenge

Intuitive Analytics wanted to develop a set of quantitative tools that minimizes the expected cost or risk a government incurs when managing a capital structure.

Solution (with the help of MathWorks' Consulting)

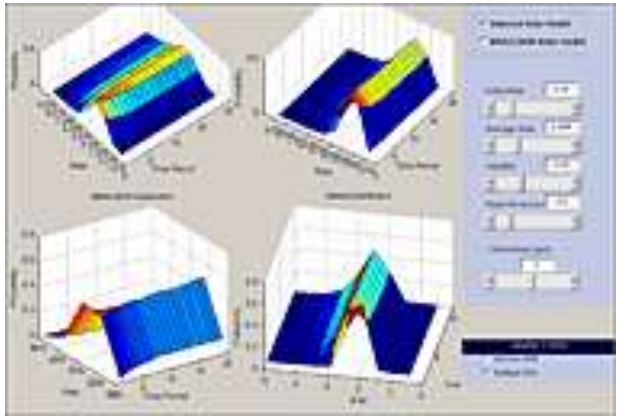
- Able to use MathWorks tools to develop algorithms, visualize results, and simplify deployment of an advanced analytical tool

Value

- Development productivity increased by 90%
- Deployment simplified
- Visual environment created

For more information:
http://www.mathworks.com/tagteam/51834_91408v02_intutive.pdf

"I estimate that we can develop 90% faster with MathWorks tools than we could with C/C++ or Visual Basic." - Peter Orr, Intuitive Analytics, Inc.



Using MATLAB development tools to provide visual representations of interest rate models

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