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Dynamic Solutions Precise Results

MATLAB & SIMULINK DAY 2013

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Automatic C Code Generation from MATLAB

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AGENDA

- Quick Demo
- Benefits of Automatic C Code Generation
- In-Depth Example
- Comparison between MATLAB Coder and MATLAB Compiler
- Fixed-Point Design
- Conclusion

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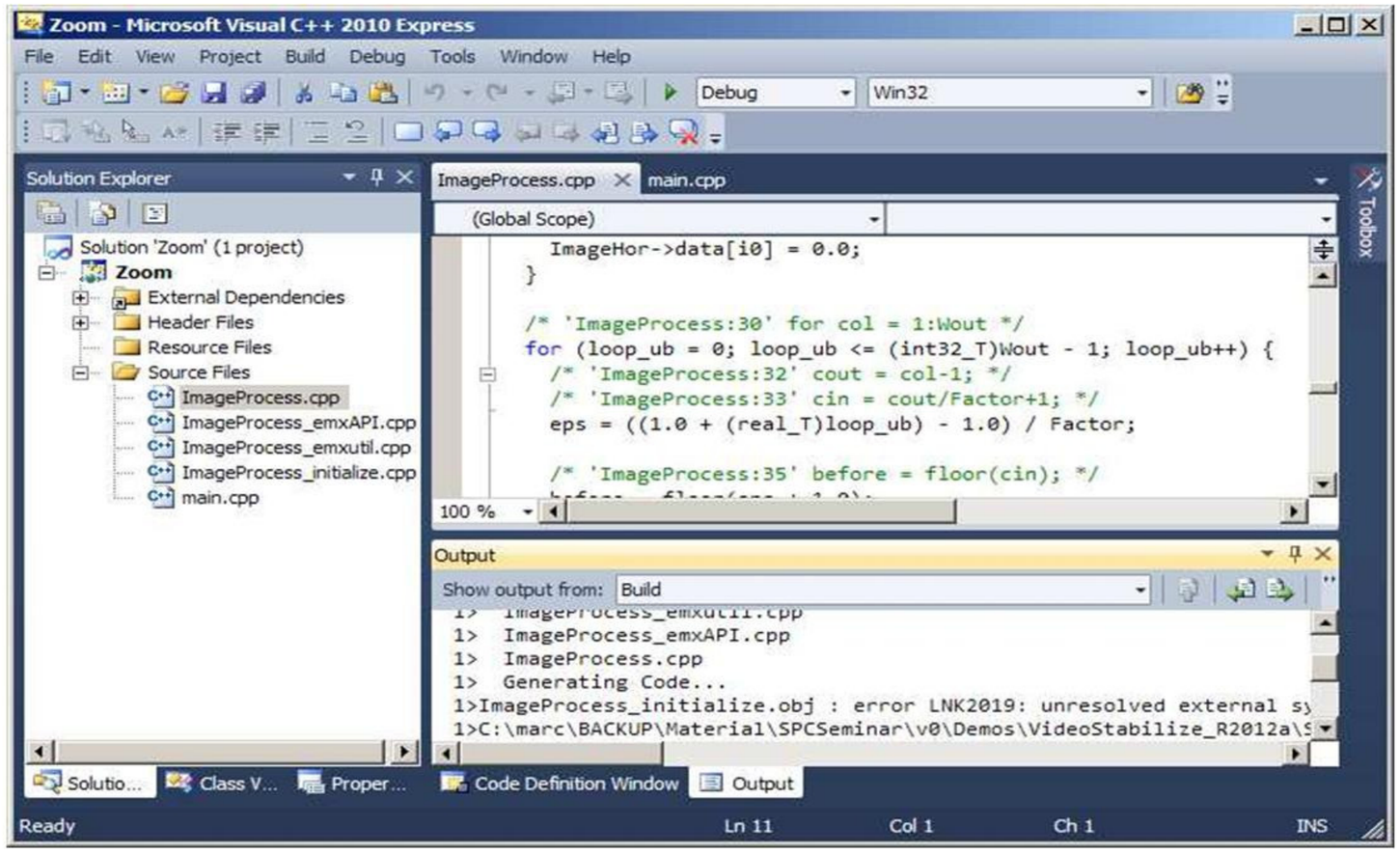
Demo: Using Generated C Code in a Stand-Alone C Project



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Why translate MATLAB to C?

Integrate MATLAB algorithms w/ existing C environment using source code or static libraries

Prototype MATLAB algorithms on desktops as standalone executables

Accelerate user-written MATLAB algorithms

Implement C/C++ code on processors or hand-off to software engineers

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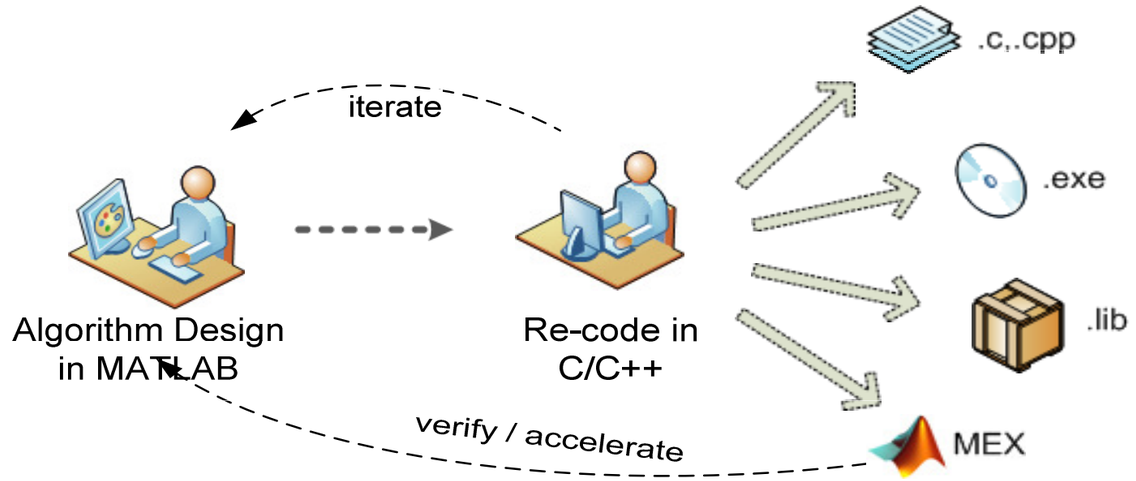
Challenges with Manual Translation from MATLAB to C/C++



- Separate functional and implementation specification
  - Leads to multiple implementations that are inconsistent
  - Hard to modify requirements during development
  - Difficult to keep reference MATLAB code and C code in-sync
- Manual coding errors
- Time consuming and expensive

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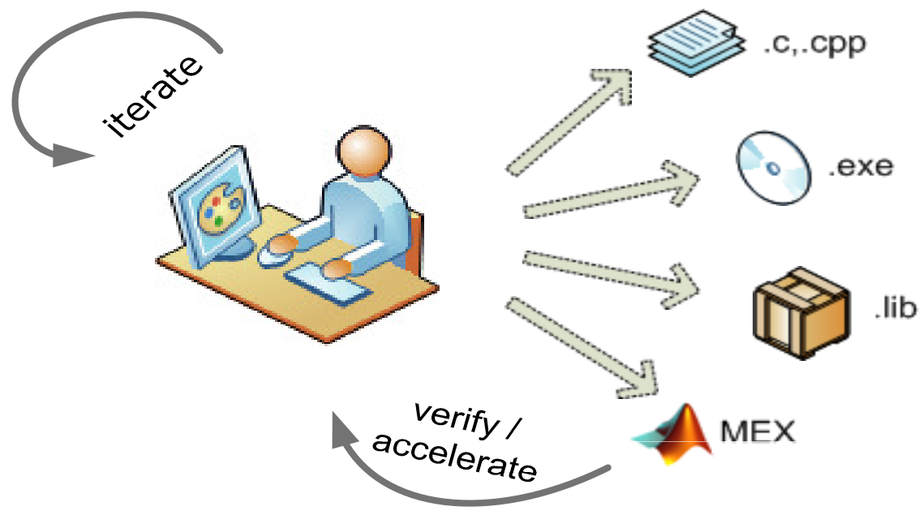
Automatic Translation of MATLAB to C

Algorithm Design and Code Generation in MATLAB



With MATLAB Coder, design engineers can

- Maintain one design in MATLAB
- Design faster and get to C/C++ quickly
- Test more systematically and frequently
- Spend more time improving algorithms in MATLAB

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Implementation Constraints

function a= **foo(b,c)**
a = b * c;

- Element by element multiply
- Dot product
- Matrix multiply

logical
integer
real
complex
…

C

```
double foo(double b, double c)
{
        return b*c;
}
```

```
void foo(const double b[15],
         const double c[30], double a[18])
{
  int i0, i1, i2;
for (i0 = 0; i0 < 3; i0++) {
   for (i1 = 0; i1 < 6; i1++) {
     a[i0 + 3 * i1] = 0.0;
     for (i2 = 0; i2 < 5; i2++) {
       a[i0 + 3 * i1] += b[i0 + 3 * i2] * c[i2 + 5 * i1];
     }
   }
  }
}
```

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Implementation Constraints

- Polymorphism
- Memory allocation
- Processing matrices & arrays
- Fixed-point data types

7 Lines of MATLAB
107 Lines of C

```
function [x_est p_est] = kalman_estimate(R,H,x_prd,p_prd,z)
S = H * p_prd' * H' + R;
B = H * p_prd';
klm_gain = (S \ B)';
x_est = x_prd + klm_gain * (z - H * x_prd);
p_est = p_prd - klm_gain * H * p_
```

```
#include "kalman_estimate.h"

void kalman_estimate(const real_T R[4],
                     const real_T p_prd
                     x_est[6], real_T p
{
  int32_T r1;
  int32_T r2;
  real_T klm_gain[12];
  int32_T k;
  real_T a21;
  real_T S[4];
  real_T B[12];
  real_T a22;
  real_T Y[12];
  real_T b_z[2];
  real_T b_klm_gain[36];
  for (r1 = 0; r1 < 2; r1++) {
    for (r2 = 0; r2 < 6; r2++) {
      klm_gain[r1 + (r2 << 1)] = 0.0;
```

```
for (r1 = 0; r1 < 2; r1++) {
  a21 = 0.0;
  for (r2 = 0; r2 < 6; r2++) {
    a21 += H[r1 + (r2 << 1)] * x_prd[r2];
  }

  b_z[r1] = z[r1] - a21;
}

for (r1 = 0; r1
  a21 = 0.0;
  for (r2 = 0;
    a21 += klm_
  }

  x_est[r1] = x
}

for (r1 = 0; r1
  for (r2 = 0;
```

```
if (fabs(S[1]) > fabs(S[0])) {
  r1 = 2;
  r2 = 1;
} else {
  r1 = 1;
  r2 = 2;
}

a21 = S[r2 - 1] / S[r1 - 1];
a22 = S[r2 + 1] - a21 * S[r1 + 1];
for (k = 0; k < 6; k++) {
  Y[1 + (k << 1)] = (B[(r2 - 1) + (
    a22;
  Y[k << 1] = (B[(r1 - 1) + (k << 1
    1];
}

for (r1 = 0; r1 < 2; r1++) {
  for (r2 = 0; r2 < 6; r2++) {
    klm_gain[r2 + 6 * r1] = Y[r1 + (r2 << 1)];
```

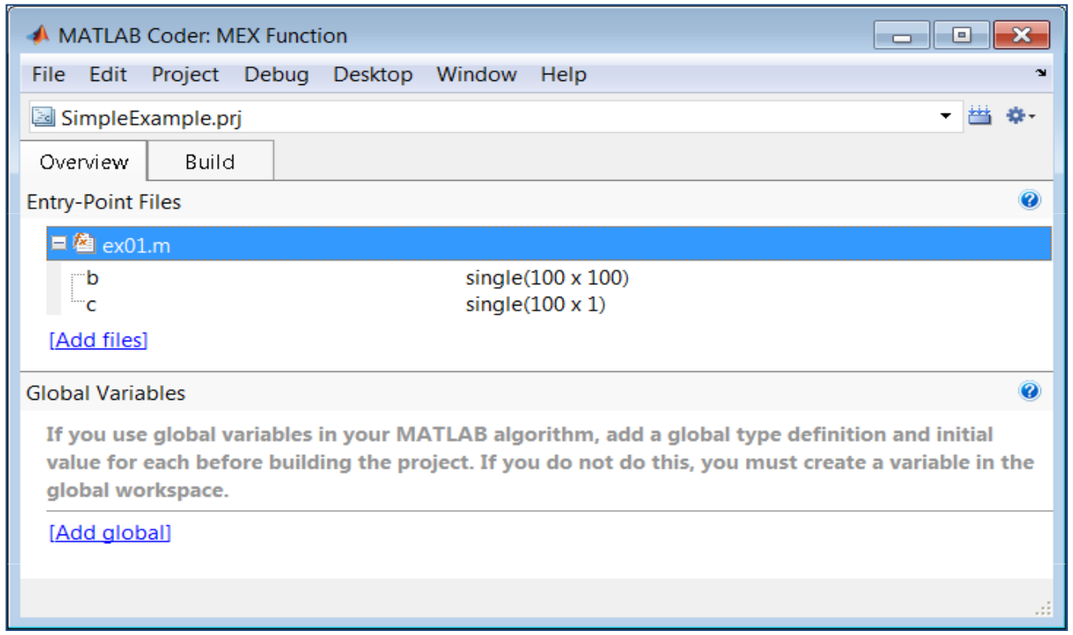
```
for (r1 = 0; r1 < 2; r1++) {
  for (r2 = 0; r2 < 2; r2++) {
    a21 = 0.0;
    for (k = 0; k < 6; k++) {
      a21 += klm_gain[r1 + (k << 1)] * H[r2 + (k << 1)];
    }

    S[r1 + (r2 << 1)] = a21 + R[r1 + (r2 << 1)];
  }
}

for (r1 = 0; r1 < 2; r1++) {
  for (r2 = 0; r2 < 6; r2++) {
    B[r1 + (r2 << 1)] = 0.0;
    for (k = 0; k < 6; k++) {
      B[r1 + (r2 << 1)] += H[r1 + (k << 1)] * p_prd[r2 + 6 * k];
    }
  }
}
```

In-Depth Demo of MATLAB Coder

- Coder UI
- Code Generation options
- Generate code
- Browse through report



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Supported MATLAB Language Features and Functions

- Broad set of language features and functions/system objects supported for code generation

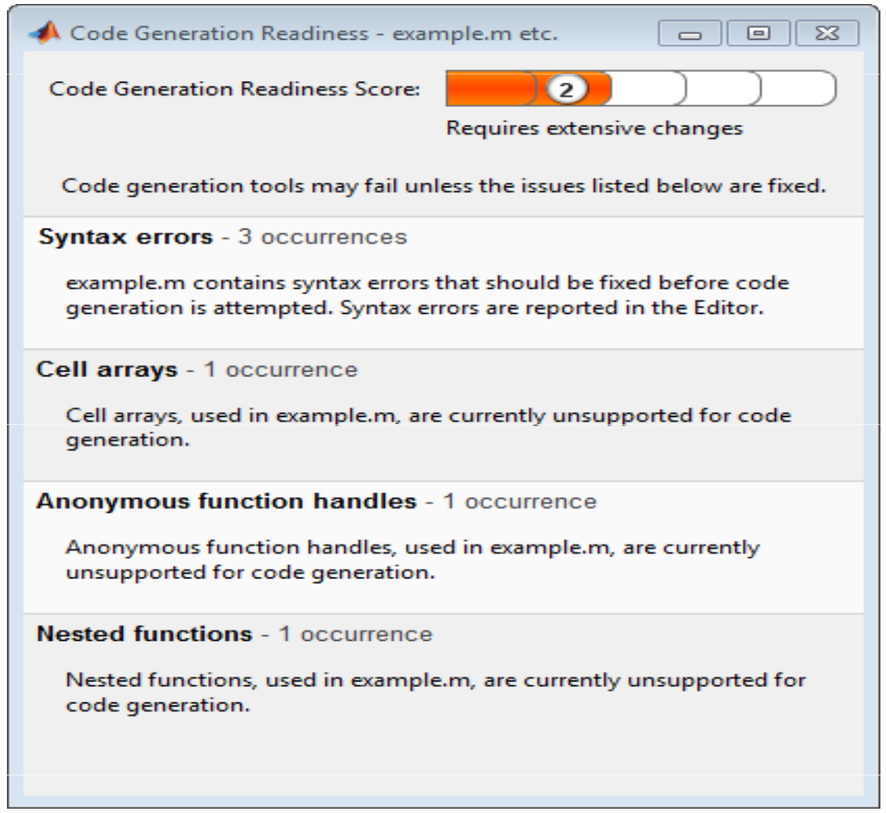
Matrices and Arrays	Data Types	Programming Constructs	Functions

• Matrix operations
• N-dimensional arrays
• Subscripting
• Frames
• Persistent variables
• Global variables
	• Complex numbers
	• Integer math
	• Double/single-precision
	• Fixed-point arithmetic
	• Characters
	• Structures
	• Numeric classes
	• Variable-sized data
	• System objects
	• Classes
		• Arithmetic, relational, and logical operators
		• Program control (if, for, while, switch)
			• MATLAB functions and sub-functions
			• Variable length argument lists
			• Function handles
			
			Supported algorithms
			• > 400 MATLAB operators and functions
			• > 200 System objects for
			  • Signal processing
			  • Communications
			  • Computer vision

Code Generation Readiness Tool

Instant feedback on code generation compliance of your MATLAB code

- Provides estimate of effort needed to generate C code from your MATLAB code on a scale of 1 to 5
- Provides a list of issues that need to be resolved in one report
- Gives detailed information on unsupported functions



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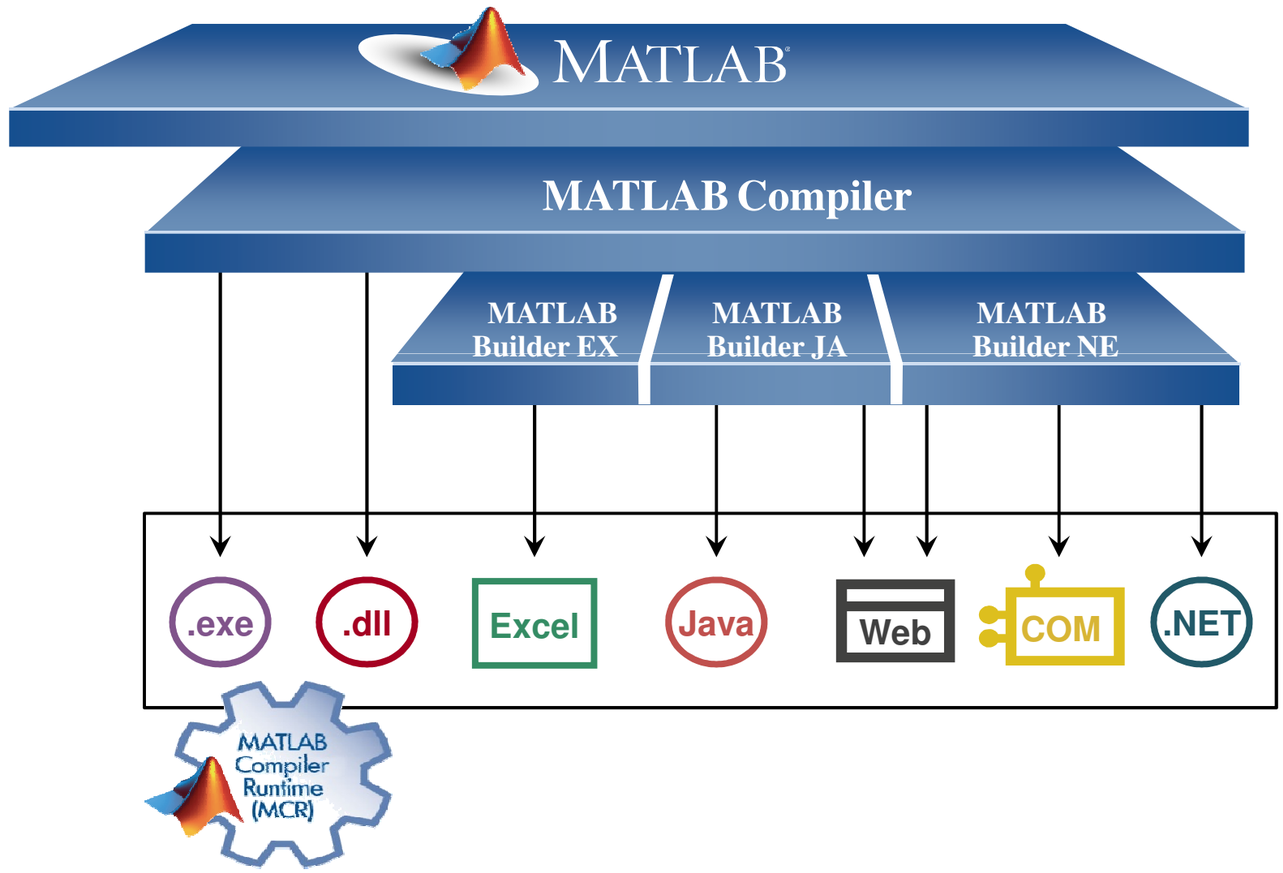
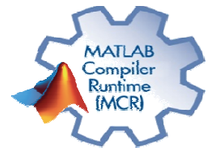
Other Deployment Options
Deploying Applications with MATLAB Compiler

- Share applications
  - Desktop or Web software components
  - Supports full MATLAB language and most toolboxes
  - Requires MCR
    - Free run-time library
    - Royalty-free deployment



Choosing the Right Deployment Solution
MATLAB Coder and MATLAB Compiler



	MATLAB Coder	**MATLAB Compiler**
Output	Portable and readable C source code	Executable or software component/library
MATLAB support	Subset of language Some toolboxes	Full language Most toolboxes Graphics
Runtime requirement	None	MATLAB Compiler Runtime (MCR)
License model	Royalty-free	Royalty-free

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Fixed Point Design: Motivation

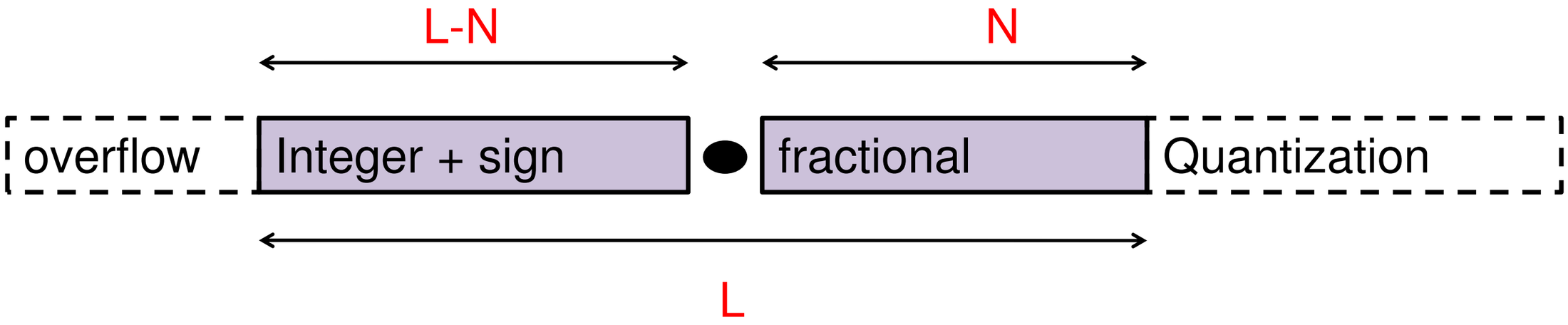
Consideration	Fixed Point	Floating Point
RAM and ROM consumption	Small	Large
Execution time	Faster	Slower
Hardware power consumption	Low	High
Development time	Long	Short
Implementation complexity	More complex. Control of word length, rounding mode, saturation...	Less
Error Prone	Harder to develop. More prone to programming errors	Easier to develop

Fixed Point Design: Pitfalls

- Arithmetic Pitfalls
  - Introduces quantization errors
  - Word length and Fraction Length must be specified
    - For every variable
  - Degradation must be analyzed

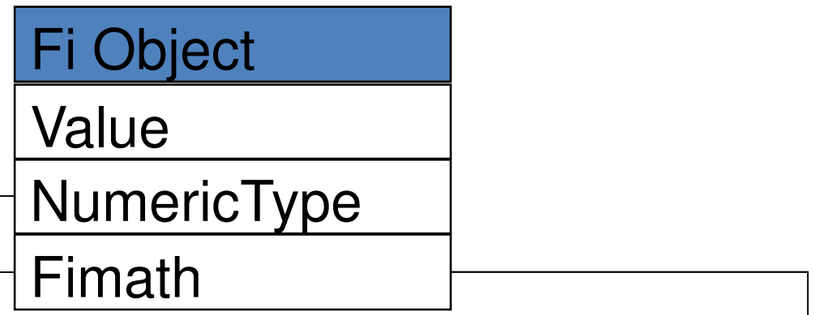
Fixed Point Design: Pitfalls

- Fixed Point C Pitfalls
  - No native fixed-point math libraries
  - No built-in *overflow* / *underflow* checks
  - No tools to determine optimal *integer* and *fractional* bits
  - No visualization of floating and fixed-point representations



Fixed-Point Toolbox:
MATLAB Fixed-Point Object

```
Signed: true
WordLength: 16
FractionLength: 13
```




```
RoundMode: round
OverflowMode: saturate
ProductMode: FullPrecision
MaxProductWordLength: 128
SumMode: FullPrecision
MaxSumWordLength: 128
CastBeforeSum: true
```

1. Controls output type of operations
2. Allows natural operator syntax

A*B, A+B, pow2(A,3)

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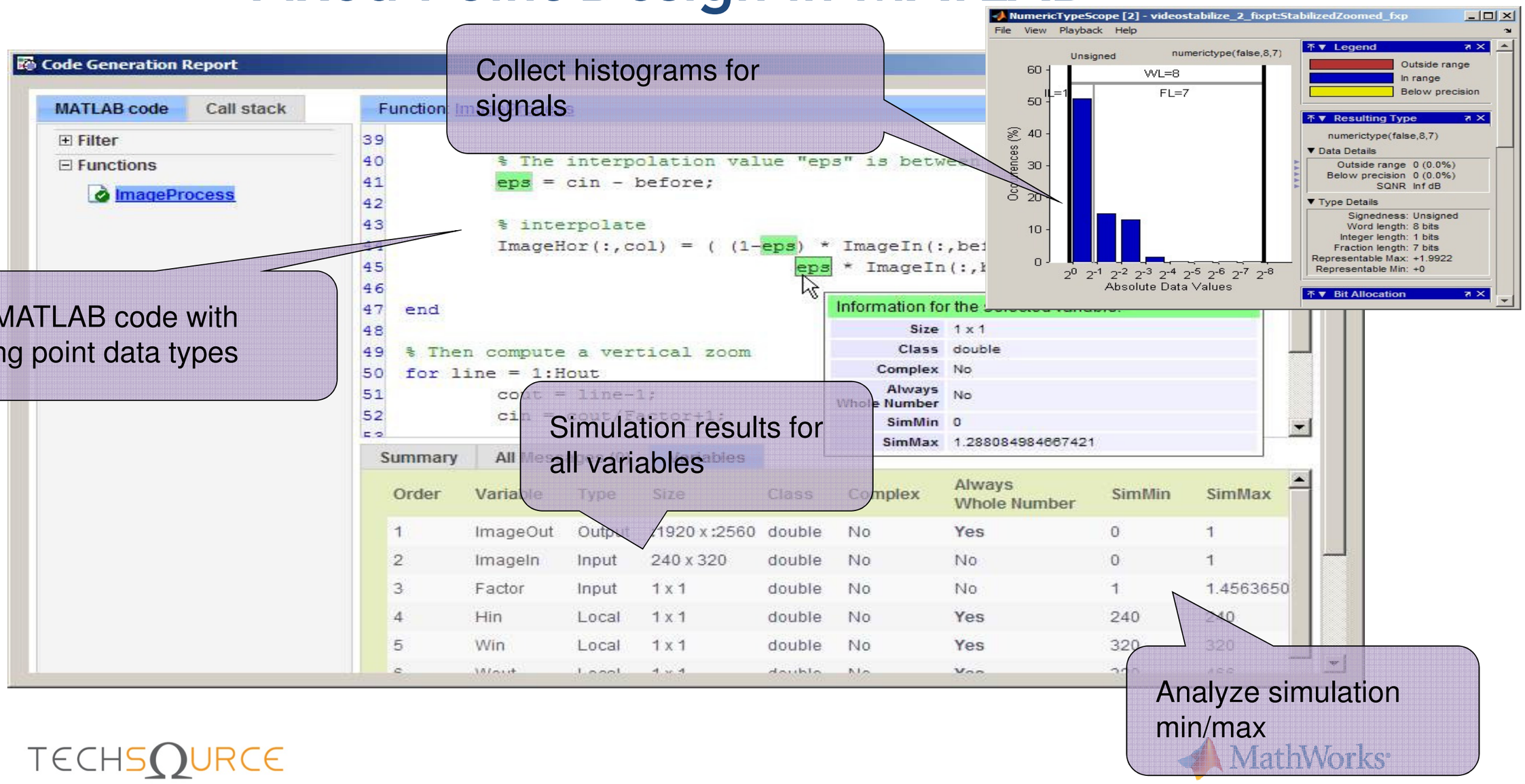
Fixed Point Design in MATLAB



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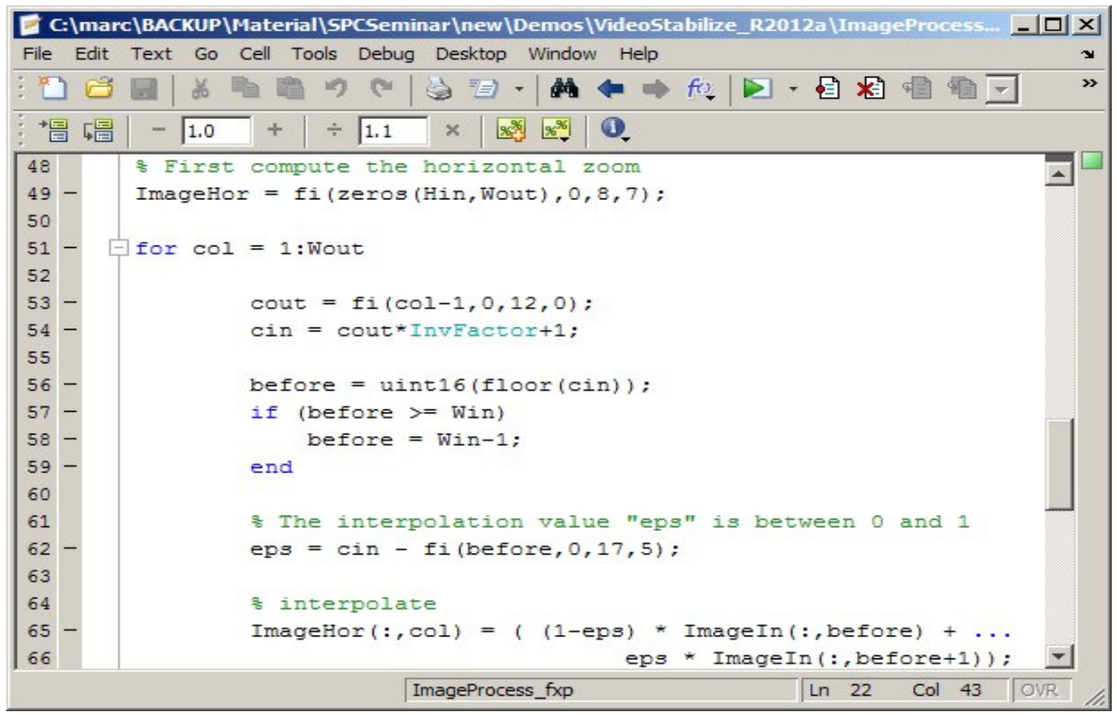
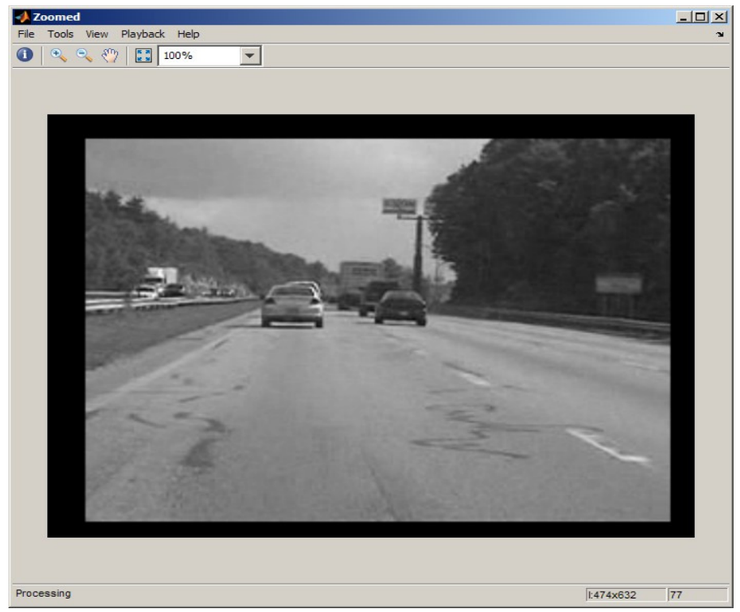
Demo: Fixed Point Design in MATLAB

- Determine best fixed-point settings
- Simulate the fixed-point code
- Generate fixed-point C code





Benefits of C Code Generation with MATLAB Coder

- Generate C code directly
  - Automatically generated C code is correct by construction
  - Reduce verification effort and cost
- Maintain floating and fixed-point designs in a unified environment
  - Run simulations in double precision or fixed-point as needed
  - Validate fixed-point effects during system design phase

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