ID.Fix
Optimisation de la précision des calculs dans les systèmes embarqués : méthodes et outils
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Number Representation

- Floating-Point
  \[ x = (-1)^s \times m \times 2^{e-127} \]
  - \( s \): sign, \( m \): mantissa, \( e \): exponent

- Pros and cons
  - Simple to use
  - High dynamic range
  - but
  - Accuracy problems
  - Complex operators

- Fixed-Point Numbers
  \[ x = (-1)^s (-2)^m + \sum_{i=-n}^{m-1} b_i 2^i \]
  - \( s \): sign, \( m \): magnitude, \( n \): fractional
  - Efficient operators
  - Stable, predictable
  - but complex to use, overflow, precision loss
Fixed-Point Arithmetic

- Dynamic range $[-2^m, 2^m]$
- Precision: $2^{-n}$
- Arithmetic rules
  - Multiplication, addition: $(\text{int})(((\text{INT64})a * (\text{INT64})b) >> N)$
  - Scaling operations are explicit in software code
- Precision (noise) | Overflow
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1.640625</td>
<td>1.640625</td>
</tr>
<tr>
<td>+ 2.3125</td>
<td>+ 2.5125</td>
</tr>
<tr>
<td>= 3.953125</td>
<td>= 4.153125</td>
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Fixed-Point Arithmetic

- Speed, power, cost
- Efficient computation
  - Faster execution time
    - Fix/float: ratio of 9
  - Energy efficient (us/mW)
    - Fix/float: ratio of 5
  - Cost efficient (us/$)
    - Fix/float: ratio of 5
  - (DSP C6x from TI)
- Stable calculations across platforms
  - Predictable by simulations
- Accuracy is limited but often sufficient for many applications
Fixed-Point Arithmetic is Mainstream in Embedded Systems

- Many application domains
  - Telecommunications, wireless
    - e.g. wireless receiver is sampled with low precision
    - e.g. error-correcting codes still work for very-low precision
  - Signal and image processing, audio, video
  - Control (automotive)
  - Graphics (OpenGL ES 1.x)

Fixed-Point Arithmetic is Mainstream in Embedded Systems

- Most of embedded platforms use only fixed-point arithmetic
  - Embedded processors, microcontroller, digital-signal processors, application platforms
  - FPGA, system-on-chip
  - FPU is big and hot!
Fixed-Point Conversion

- Determine the number of bits for each data
  - Range estimation: integer part word-length
  - Precision estimation: fractional part word-length
- Insert scaling instructions after every operations
  - Arithmetic rules
- Manual conversion
  - Long, tedious and error-prone
    - 25% to 50% of the total design time (according to Mathworks)
- Strong need of tools to reduce the time-to-market

Fixed-Point Conversion

- Existing tools for helping the designer in the fixed-point conversion process
  - Fixed-point Matlab Toolbox (Mathworks)
  - AcceleDSP (Xilinx)
  - Catalytic (Mentor Graphics)
- Performance evaluation using bit-true simulation
  - Fixed-point simulation is very long
  - Data word-length optimisation time is prohibitive
  - Limited design space exploration
ID.Fix
A Framework for Fixed-Point Conversion

- Source-to-source code transformation
  - C with float to C/VHDL using fixed-point types
  - Compiler framework: GECOS (Eclipse)

- Contracts
  - ANR ROMA
  - Nano 2012 (STMicro.)
  - INRIA: engineer

ID.Fix
A Framework for Fixed-Point Conversion

**Highlights** from ID.Fix tool

- **Analytical estimation of accuracy**
  - Output noise power $P_0$ is a mathematical expression which is formulated for every data wordlengths
  - $P_0$ can be linked to application performance
    - with system-level floating-point simulations
    - e.g. BER (bit error rate), PSNR (peak signal-to-noise ratio)

- System-level estimation and design space exploration are possible
- Optimisation time of the process is significantly reduced
ID.Fix
A Framework for Fixed-Point Conversion

- Automatic conversion from floating-point to fixed-point
- Wordlength optimisation
  - Cost minimisation under accuracy constraint

\[ \min_j \left[ T_{\text{exec}} (W_L) + \text{Cost} (W_L) \right] \]
\[ SQNR(W_L) \geq SQNR_{\text{min}} \]

Conclusion

- Fixed-point arithmetic in embedded systems
- State-of-the-art tools are limited by long simulation time
- ID.Fix is a framework for automatic fixed-point conversion and design-space exploration
- Current work
  - Hierarchical approach for system-level estimation
  - Extension of source code support in the compiler