Embedded C

for

High Performance DSP Programming with the CoSy Compiler Development System

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ACE Associated Compiler Experts

- **Home of CoSy**
  the compiler development system
  - Compiler Generator System
  - Modular design
  - Configurable
  - Retargetable
  - Robust
  - Extensible
  - High Quality
  - Highly optimising

Japan Novel and CoSy

- Japan Novel is an exclusive agent in Japan for ACE
- Japan Novel provides a products and services to improve the quality of today's complex embedded software
  - Compiler evaluation services
  - Automated test&evaluation system - Quality Commander
  - C/C++ comformance test suites - PlumHall's products
- Compiler evaluation services provide a thorough testing of C/C++, Embedded－C, DSP-C compilers
- With it's high reliability, CoSy compiler development system contributes to the embedded system development in Japan

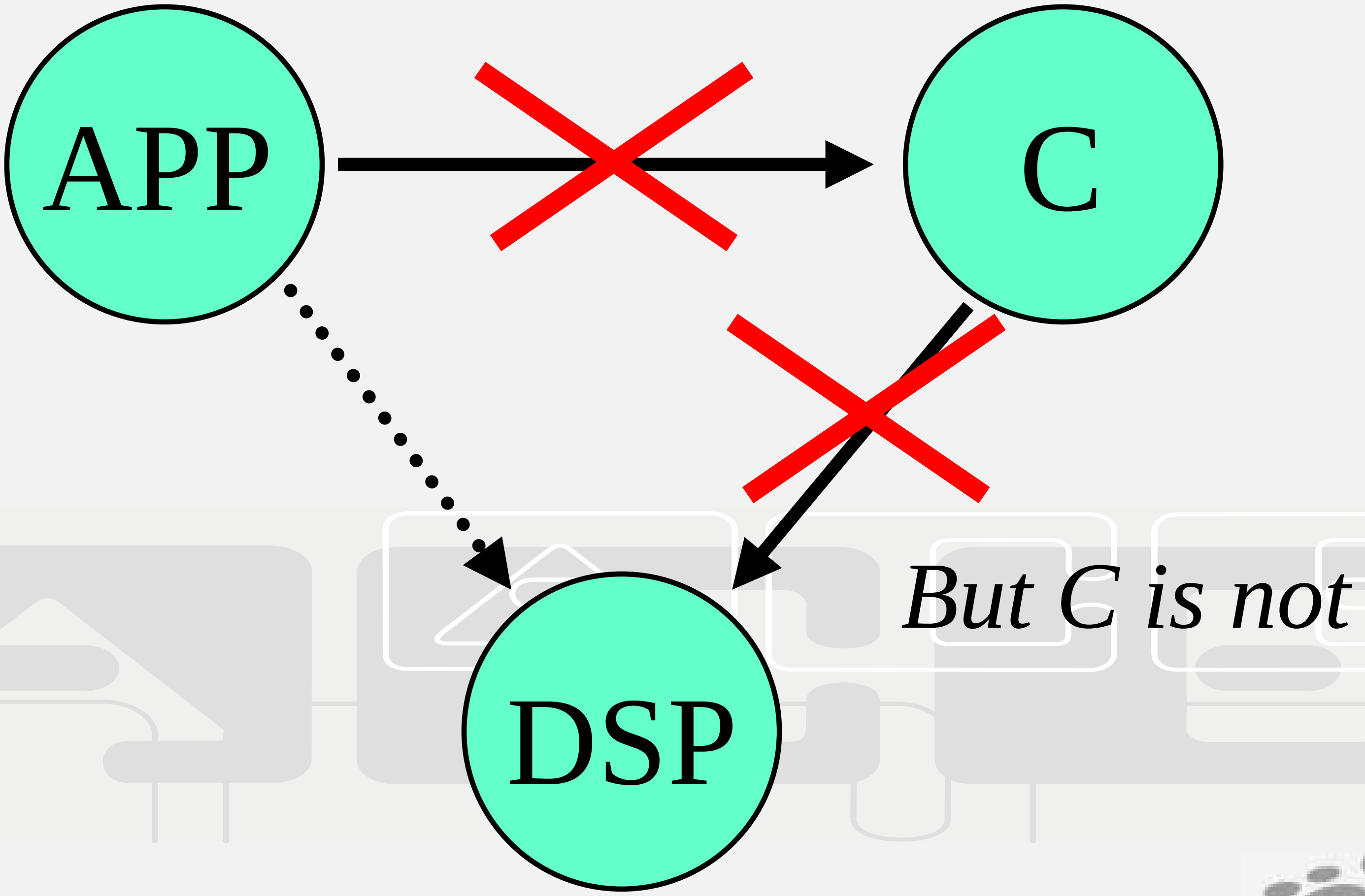
Programming DSPs in C has many advantages

- **Code portability allows switching to another DSP >>> *No CPU lock-in***
- **Software engineering quality is much better than assembly >>> *Faster time to market***
- **No dependency on specialist assembly programmers >>> *Lower Cost/Time to market***

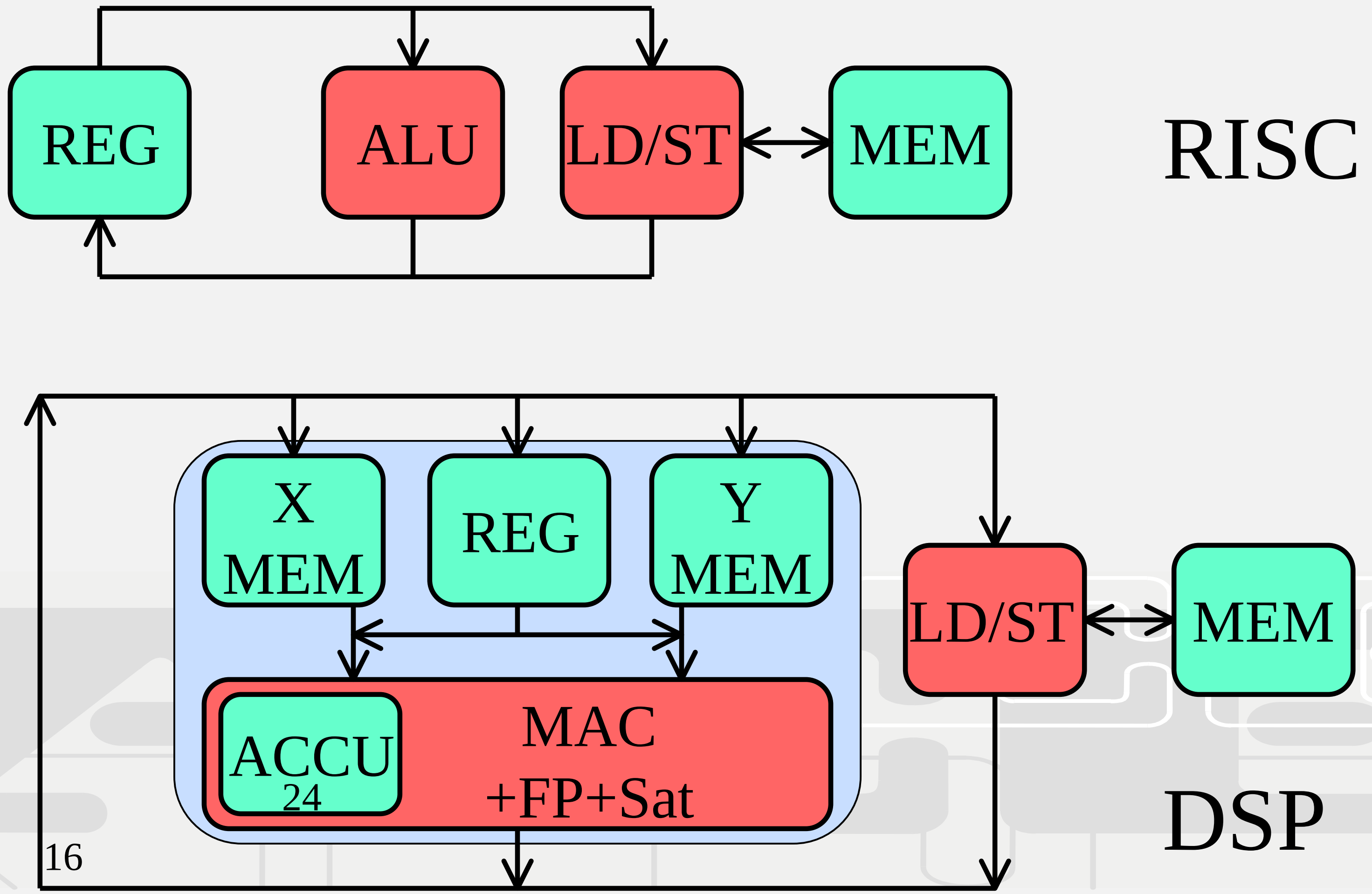
…But still DSP assembly programming is used very often because of

Performance Requirements

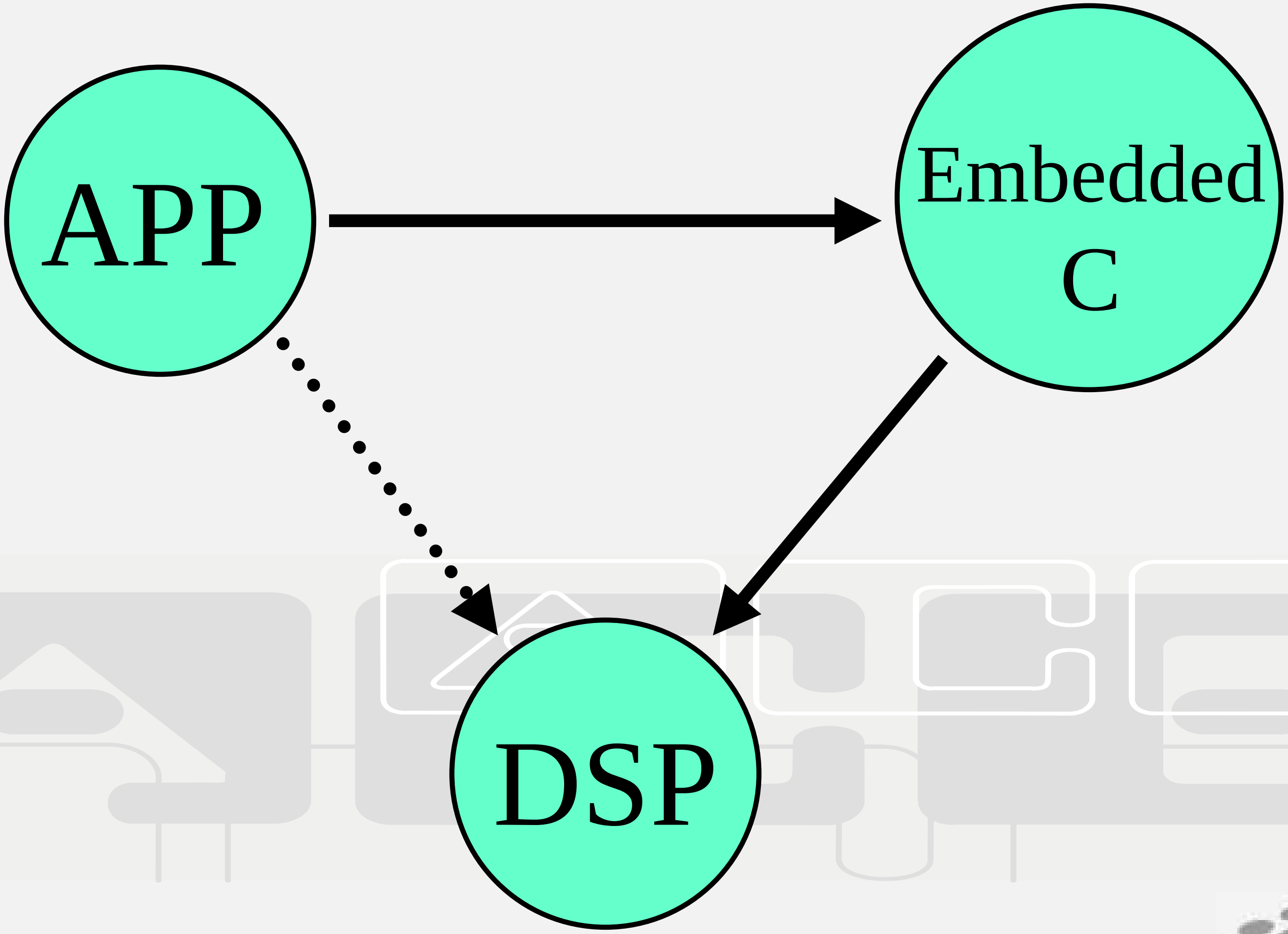
DSP Processors are Adapted to the Application



RISC vs. DSP Architecture



Enter *Embedded C*



Embedded C

- Based on the DSP-C extension, an industry standard by ACE
- Unlocks the performance potential of embedded processor features to the high level language programmer
- Promotes portability
- Adds fixed-point, saturation, named address spaces and I/O access to C

Status of Embedded C

- **Defined in a technical report by ISO (TR18037)**
- **Ratified in February 2004**
- `www.open-std.org/jtc1/sc22/wg14/`

Fixed-Point Type: `_Fract`

- Range of `[-1.0, 1.0>`
- Has a fractional part only, no integer part
- Efficiently implemented on top of two's complement arithmetic
- Variants for `short` and `long`
- Accuracy defined by implementation/architecture

`_Accum` Type

- Also has an integer part, for example a range of `[-256.0, 256.0>`
- Designed as an intermediate value for fixed-point arithmetic
- Not meant to be a storage type
- Also `short` and `long` variants with accuracy matching the `_Fract` variants

Saturation: `_Sat` Qualifier

- **Makes computations saturate:**
  `-0.75r + -0.75r == -1.0r`
- **No storage implications**
- **Needed because signal processing applications often operate at the boundary of the range to get best S/N**

Named Address Spaces

- No predefined keywords
- Examples:

```
X int a[25] ;
X int * Y p ;
```

- Restrict access to a specific part of the address space
- Unrestricted (general) pointers can access all address spaces

Example

```
X fract coeff[N] = { 0.7r, ... } ;

fract fir( Y fract *inp ) {
    int i ;
    accum sum = 0.0k ;
    for( i = 0 ; i < N ; i++ ) {
        sum += coeff[i] * (accum)*inp++ ;
    }
    return (sat fract)sum ;
}
```

Performance Comparison Based on DSP-C

- **Using the CoSy DSP-C compiler for internal Ericsson telecom processor (16-bit, VLIW, dual MAC, dual 32-bit ld/st)**
- **Using the CoSy DSP-C compiler for the NEC µPD77016 processor (16-bit standard DSP)**
- **Compare:**
  - **Basic operations**
  - **NEC applications**
  - **MiBench loop**

Thanks to Ericsson, NEC and University of Michigan

Basic Operations

- **Using the Ericsson compiler, highest performance settings**

	ISO C Cycles/Size	*CoSy DSP-C* Cycles/Size
Saturation	10/46	0*/0*
FIR-filter	2/74	1*/26
Array Copy	2/12	1*/12

Cycles: in inner loop, except for saturation
Results marked with * are optimal

NEC Applications

Using the NEC µPD77016 CoSy compiler
Reporting total clock cycles for application

	ISO C	*CoSy DSP C*	*Ratio*
Control	3946	3890	1.0
DSP 1	5144	550	9.4
DSP 2	168546	48064	3.5
DSP 3	2822	349	8.1

Near 10 times improvement! How?

MiBench Original Code

- **Taking procedure from telecom/gsm:** `Short_term_analysis_filtering`
- **Inner loop :**

```
for (i = 0; i < 8; i++) {    /* YYY */
      ui    = u[i];
      rpi   = rp[i];
      u[i]  = sav;
      zzz   = GSM_MULT_R( rpi, di  );
      sav   = GSM_ADD   ( ui,  zzz );
      zzz   = GSM_MULT_R( rpi, ui  );
      di    = GSM_ADD   ( di,  zzz );
}
```

MiBench DSP-C Code + Accum

- **Rewritten in DSP-C, with accumulator use**

```
for (i = 0; i < 8; i++) {     /* YYY */
    ui   = u[i];
    rpi  = rp[i];
    u[i] = sav;
    sav  = ((long accum)ui) + rpi * di ;
    di   = ((long accum)di) + rpi * ui ;
}
```

MiBench Loop

- **Using the Ericsson compiler, highest performance settings, report cycles in inner loop**

	ISO C Cyc./Size	*CoSy DSP-C* Cyc./Size	*DSP-C+ accum* Cyc./Size
`S_t_a_f`	32/228	4/112	3*/112

Results marked with * are optimal

MiBench Loop Results Explained

- **Original code uses *macros* to write maintainable code, but results in unnecessary saturation in inner loop**
- **Fixed point emulation code in plain ISO C requires more registers; with a limited register file this results in *spill-code***
- **Cumulative effect explains factor 10 overhead in the inner loop**

Embedded C in CoSy

- Full front-end support for Embedded C
- Configurable data type sizes
- Fully integrated with Compiler IR
- Optimized by CoSy optimization modules
- Full emulation and support library included
- Example emulation compiler included
- Compiler generation for Windows, Linux, Solaris
- DSP-C available in CoSy since 1998
- Embedded C available in CoSy 2005

The Embedded C world

- C compilers with DSP extensions have been developed for: Philips REAL, Adelante Saturn, NEC µPD77111/210, TI TMS320C54x, Analog Devices SHARC, MMDSP+, META RISC/DSP and many more …
- Used and supported by: ACE, Ericsson, AbsInt, NullStone, Mentor Graphics XRAY, Japan Novel, …

Benefits of Embedded C

- Enables high level language code for embedded processors that runs efficiently
- Standardizes the notation of common performance features in DSP architectures
- Standardizes I/O hardware access
- Thereby considerably improving the software engineering and portability of embedded applications
- Economic advantages: time to market, flexibility

Use CoSy with Embedded C!

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Implicit Promotions

```
_Fract f = (_Fract)(0.1r * 2.5) ;
```

- **Rank order:** `int`, `_Fract`, `_Accum`, `float`
- **New concept (for C), mixed type arithmetic:**

```
f = 3 * 0.1r ;
```

Only for mixing int and fixed point

`unsigned` Fixed-Point Variants

- **Range:** `[0.0, 1.0>`
- **Useful for image processing**
- **Not implemented by all DSP processors (saturation)**

Features That Did Not Make It

- Circular buffers
- `_Modwrap` qualifier for modulo fixed-point arithmetic
- Complex fixed-point type
- BCD data types

Performance vs. Portability of Embedded C (1)

- **Accuracy of fixed-point types is not guaranteed, while most DSP algorithms rely on a particular accuracy**
- **Memory qualifier keywords are not predefined by Embedded C**
- **Similar to existing practice in C**

So, 100% portability of Embedded C programs is not guaranteed

Portability of Embedded C (2)

- The Embedded C implementation must match the target processor
- Example: A 24-bit accuracy DSP application can not run efficiently on a 16-bit DSP processor
- Embedded C implementation allows for adaptation specific to the architecture

NEC Code Size Comparison, Bytes

	ISO C	DSP-C	Ratio
Control	442	414	1.1
DSP 1	350	90	3.9
DSP 2	2152	1155	1.9
DSP 3	3807	2781	1.4

I/O Hardware Addressing

- **Aims to allow for portable device driver source code**
- **Based on a three level model**

Portable driver source code
I/O register definitions
Vendor IOHW implementation

- **Still allows for minimal overhead implementation**