Embedded Software Generation from System Level Design Languages

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Outline

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- **Design flow**
- **Embedded software generation**
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  - Code generation
  - Operating System targeting
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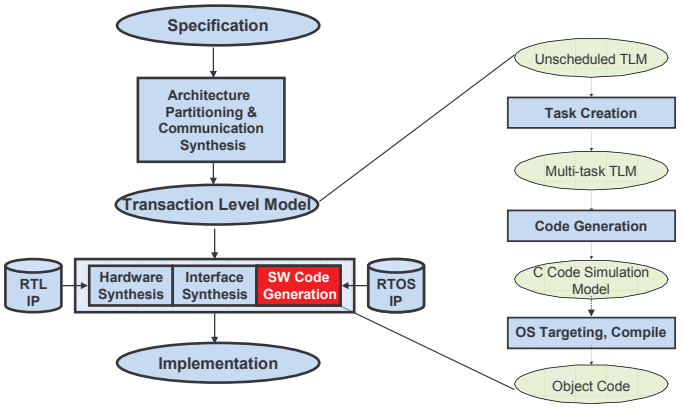
Introduction

- **Increasing Significance of Embedded SW**
  - ⇨ Most embedded software is still created manually after HW/SW partitioning
  - ⇨ Generation from system level design language (SLDL) is one solution to increase productivity
- **Embedded SW Generation within System Design Flow**
  - Sequence of refinement steps
  - Well-defined intermediate models
- **Implementing SLDL language elements using ANSI C**
  - Hierarchy, concurrency, communication
  - Modules, processes, channels, port mappings

Related Work

- **Code generation**
  - From abstract model (UML) [Rational]
  - From graphical finite state machine (StateCharts) [Harel90]
  - From synchronous programming languages (Esterel)[Boussinot91]
- **POLIS approach [Baladrin97]**
  - Mainly focused on reactive real time systems
  - Not easily extended for other more general frameworks
- **Software generation from SystemC SLDL**
  - Redefinition and overloading of SystemC class [Herrera03]
    - Requires C++ compiler and introduces SLDL language overhead
  - Substituting SystemC modules with C structures [Groetker03]
    - Requires special SystemC modeling styles

Embedded Software Generation in System Design Flow



Embedded Software Generation Steps

1) Task creation
- Creates multiple tasks from specification
- Determine scheduling algorithm, task priorities

2) Code generation
- Create C code for each task from its SLDL description

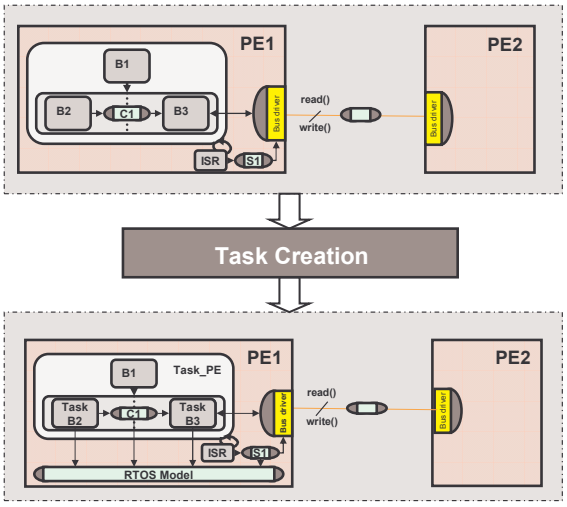
3) Operating system targeting
- Implement task management, inter-task communication

• Code optimization

Task Creation (a)

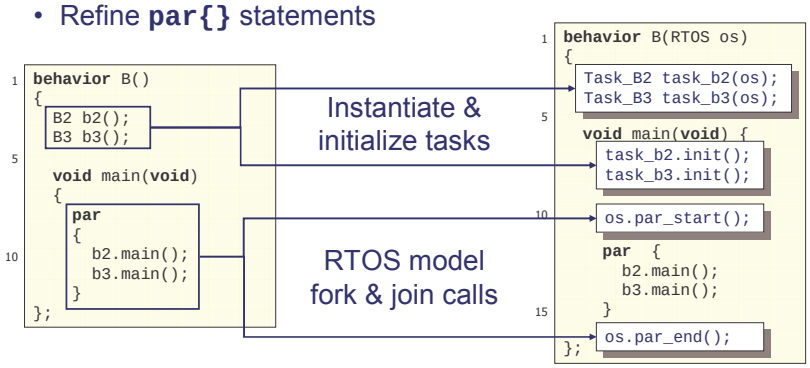
- **Concurrency**
  - Conversion of concurrent behaviors into tasks
  - Fork child tasks dynamically inside a parent task
- **Communication**
  - SLDL channels are replaced by channels from RTOS Lib
    - semaphore, queue, handshake, ...
- **Multi-task system scheduled by abstract RTOS model**
  - Choose scheduling algorithm and set task priority
  - Simulate and check timing properties for the SW part

Task Creation (b)



Task Creation (c)

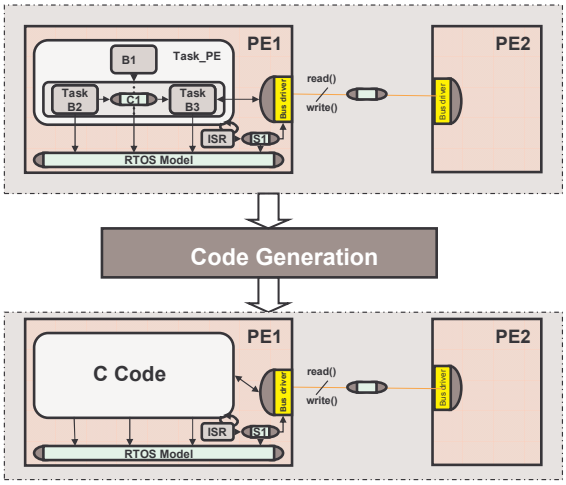
- **Dynamic task creation**
  - Refine **`par{}`** statements



Code Generation (a)

- **Rules for C code generation**
  1. Behaviors and channels are converted into C *struct*
  2. Child behaviors and channels are instantiated as C *struct* members inside the parent C *struct*
  3. Variables defined inside a behavior or channel are converted into data members of the corresponding C *struct*
  4. Ports of behavior or channel are converted into data members of the corresponding C *struct*
  5. Functions inside a behavior or channel are converted into global functions
  6. A static *struct* instantiation for each PE is added at the end of the output C code to allocate/initialize the data used by SW

Code Generation (b)



Code Generation (c)

```
behavior B1(int v)                    struct B1
{                                     {
                                        int (*v) /*port*/;
  int  a;                               int a;
                                      };
  void main(void)                     void B1_main(struct B1 *this)
  {                                   {
    a = 1;                              (this->a) = 1;
    v = a *2;                           (*(this->v)) = (this->a) * 2;
  }                                   }
};                                    struct Task1
behavior Task1                        {
{                                       int  x;
  int x;                                int  y;
  int y;                              struct B1 b11;
  B1 b11(x);                          struct B1 b12;
  B1 b12(y);                        };
                                      void Task1_main(struct Task1*this)
  void main(void)                     {
  {                                     B1_main(&(this->b11));
    b11.main();                         B1_main(&(this->b12));
    b12.main();                       }
  }                                   struct Task1 task1 =
};                                    { 0,                /* x init value*/
                                      0,                  /* y init value*/
                                      { &(task1.x),       /*port v of  b11 */
                                        0                  /* a init value */
                                      },  /*b11*/
                                      { &(task1.y),       /*port v of b12*/
                                        0                  /* a init value*/
                                      },  /*b12*/
                                    };
                                    void Task1()
                                    {
                                      Task1_main(&task1);
                                    }
```

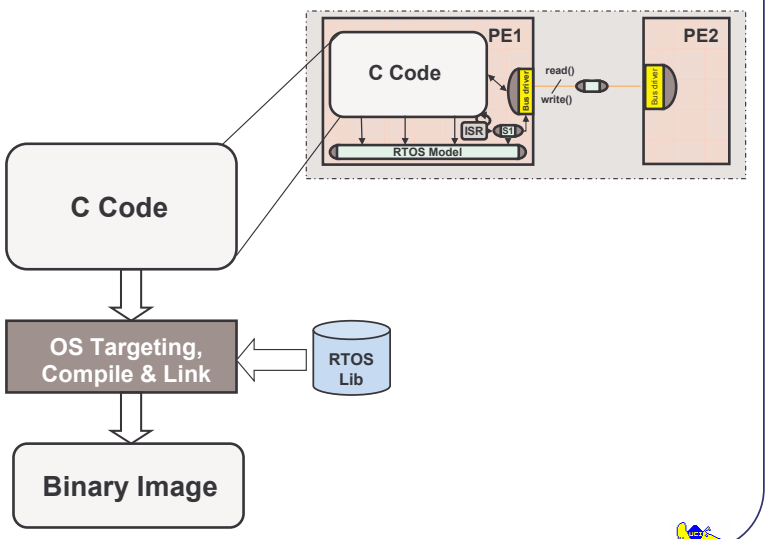
R1 R4 R3 R5 R2 R6

(a) SpecC Code (b) C Code

Operating System Targeting (a)

- **Task management (Scheduling)**
  - Implementing the abstract RTOS model interfaces by specific RTOS library APIs
- **Task communication**
  - Replacing methods of abstract RTOS channels with equivalent services of the target RTOS library routines

Operating System Targeting (b)



Operating System Targeting (c)

- **Implement task management using pthread library**

```
1  behavior B2B3(RTOS os)
   {
     Task_B2 task_b2(os);
     Task_B3 task_b3(os);
5
     void main(void) {
       task_b2.init();
       task_b3.init();
10
       os.par_start();
       par  {
         b2.main();
         b3.main();
15     }
       os.par_end();
   };
```

```
struct B2B3
{ struct Task_B2 task_b2;
  struct Task_B3 task_b3;};
void *B2_main(void *arg)
{ struct Task_B2 *this=(struct Task_B2*)arg;
  ...
  pthread_exit(NULL); }
void *B3_main(void *arg)
{ struct Task_B3 *this=(struct Task_B3*)arg;
  ...
  pthread_exit(NULL); }
void *B2B3_main(void *arg)
{  struct B2B3 *this= (struct B2B3*)arg;
   int status; pthread_t *task_b2, *task_b3;
pthread_create(task_b2, NULL,
                 B2_main, &this->task_b2);
pthread_create(task_b3, NULL,
                 B3_main, &this->task_b3);

pthread_join(*task_b2, (void **)&status);
pthread_join(*task_b3, (void **)&status);

pthread_exit(NULL);
}
```


Experiment

- **GSM Vocoder (voice encoder for mobile phones)**
- **Input model: 11,557 lines of SpecC code**
- **HW/SW partitioning:**
  - HW : Custom hardware co-processor (codebook)
  - SW : ARM7DTI (other part of the spec)
- **Output:**
  - HW: 5540 lines of Verilog code
  - SW: 7882 lines of C code

Experimental Results

- **Implementation**
  - One task for voice encoding
  - Operating System uC-OSII
- **Code sizes**

	SPEC	TLM	SW(TLM)	C
Behavior/Channel	102	127	96	0
Operations	16,614	19,527	14,573	23,868
Lines (of C code)	11,557	12,606	10,920	7,882

- **Binary code for ARM**

	Code Size	Data Size
Object File from C	33KB	19KB
Final Image	47KB	28KB

Summary and Conclusion

- **Embedded SW Generation in System-level Flow**
  - Refinement steps and algorithms
  - Task creation, Code generation, OS targeting
- **Applicable to system models written in SLDL**
  - SpecC, SystemC, ...
- **Software Synthesis frees the designer from manual coding**
- **High productivity gain**
  - Automatic seconds
  - Manual months
- **Verification of the generated code becomes easier**
  - Refinement-based approach generates well-structured code
  - Intermediate models are well-defined
- **Future work**
  - Focus on SW/HW driver synthesis
  - Improvements on OS targeting part
- **Additional information**
  - `http://www.cecs.uci.edu/~cad/sce.html`