F28HS Hardware-Software Interface: Systems Programming

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[0]No proprietary software has been used in producing these slides

Outline

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Tutorial 4: Inline Assembler with gcc

- So far we have developed either C or Assembler programs separately.
- Linking the compiled code of both C and Assembler sources together we can call one from the other.
- This is ok, but sometimes inconvenient because
  - errors occur only at link time, and carry little information
  - we can't easily parameterise the Assembler code (e.g. with the `gpio` base address)
- In this tutorial we will cover **how to embed assembler code into a C program, using the `gcc` and the GNU toolchain**

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A Simple Example

Look-up the value in `val` and copy it to `val3`:

Essentials

`val` provides the input
`asm` code returns its value
`val3` receives the output

```
static volatile int val = 1024, val3;
asm(/* multi-line example of value look-up and return
    */
    "\tMOV␣R0,␣%[value]\n"          /* load the address
       into R0 */
    "\tLDR␣%[result],␣[R0,␣#0]\n"  /* get and return
       the value at that address */
    : [result] "=r" (val3)    /* output parameter */
    : [value] "r" (&val)      /* input parameter */
    : "r0", "cc" );           /* registers used */

fprintf(stderr, "Value␣lookup␣at␣address␣%x␣(expect␣%d)
    :␣%d\n", &val, val, val3);
```

[0] Sample source in sample0.c; see also ARM inline assembly blog

Example explained

- The `asm` command defines a block of assembler code that is put at that location into the C code (embedded).
- The assembler code itself is written as a sequence of strings, each starting with a TAB (`\t`) and ending with a newline (`\n`) to match usual assembler code formatting.
- Inside the strings, the code can refer to arguments provided in the "output parameter" and "input parameter" sections.
- These sections define a **name** (e.g. `result`) that can be used in the assembler code (e.g. `%[result]`), and which is bound to a concrete variable or value (e.g. `val3`).
- Think of these in the same way as formatting strings in `printf` statements.

Example explained (cont'd)

- For example the line
  `: [result] "=r" (val3)`
  says "the name `result`, which is referred to in the assembler code as `%[result]`, is bound to the C variable `val3`; moreover, it should be represented as a register (`"r"`)"
- So, what this example code does is to load the address of the C variable `val` into the register `R0`, and then to load the value at this address, i.e. the contents of the C variable `val`, into the C variable `val3`, which should be kept in a register (`"r"`)
- The last section of the `asm` block defines which registers are modified by this assembler block. This information is needed by the compiler when doing register allocation.

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GCC Extended Assembler Commands

Using gcc you can embed assembler code into your C programs, i.e. write “inline assembler” code in C.
The format for the inline assembler code is

```
asm [volatile] ( AssemblerTemplate
                 : OutputOperands
               [ : InputOperands
               [ : Clobbers ] ])
```

[0] See GCC Manual, Section “Extended Asm”

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`AssemblerTemplate`: This is a literal string that is the template for the assembler code. It is a combination of fixed text and tokens that refer to the input, output, and goto parameters.

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The format for the inline assembler code is

```
asm [volatile] ( AssemblerTemplate
                 : OutputOperands
               [ : InputOperands
               [ : Clobbers ] ])
```

`OutputOperands`: A comma-separated list of the C variables modified by the instructions in the AssemblerTemplate. An empty list is permitted.

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GCC Extended Assembler Commands

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The format for the inline assembler code is

```
asm [volatile] ( AssemblerTemplate
                 : OutputOperands
               [ : InputOperands
               [ : Clobbers ] ])
```

`InputOperands`: A comma-separated list of C expressions read by the instructions in the AssemblerTemplate. An empty list is permitted.

[0] See GCC Manual, Section “Extended Asm”

GCC Extended Assembler Commands

Using gcc you can embed assembler code into your C programs, i.e. write “inline assembler” code in C.
The format for the inline assembler code is

```
asm [volatile] ( AssemblerTemplate
                 : OutputOperands
               [ : InputOperands
               [ : Clobbers ] ])
```

`Clobbers`: A comma-separated list of registers or other values changed by the AssemblerTemplate, beyond those listed as outputs. An empty list is permitted.

[0] See GCC Manual, Section “Extended Asm”

Another Example

Using a pair data structure, the function below computes the sum of both fields.

```
typedef struct {
  ulong min;  ulong max;
} pair_t;

ulong sumpair_asm(pair_t *pair) {
  ulong res;
  asm volatile(/* sum over int values */
               "\tLDR␣R0,␣[%[inp],␣#0]\n"
               "\tLDR␣R1,␣[%[inp],␣#4]\n"
               "\tADD␣R0,␣R0,␣R1\n"
               "\tMOV␣%[result],␣R0\n"
               : [result] "=r" (res)
               : [inp] "r" (pair)
               : "r0", "r1", "cc"  );
  return res;
```

Essentials

C variable `pair` is passed as `inp`
`"r"`: keep in register
`"=r"`: the register is written to

Modifiers and constraints to the input/output operands

When mapping **names** to C **variables** or **expressions**, the following constraints and modifiers can be specified:

Constraint	Specification
`f`	Floating point registers f0 . . . f7
`r`	General register r0 . . . r15
`m`	Memory address
`I`	Immediate value

Modifier	Specification
`=`	Write-only operand, usually used for all output operands
`+`	Read-write operand, must be listed as an output operand
`&`	A register that should be used for output only

E.g. `: [result] "=r" (res)`
means that the name `result` should be a register in the assembler code, and that it will be written to, by the assembler code.

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Extended inline assembler: Example

Using a pair data structure, the function below puts the smaller value into the `min` and the larger value into the `max` field:

```
typedef struct {
  ulong min;  ulong max;
} pair_t;

void minmax_c(pair_t *pair) {
  ulong t;
  if (pair->min > pair->max) {
    t = pair->min;
    pair->min = pair->max;
    pair->max = t;
  }
}
```

[0] Sample source: sumav1_asm.c

Extended inline assembler: Example

```
void minmax_asm(pair_t *pair) {
  pair_t *res;
  asm volatile("\tLDR␣R0,␣[%[inp],␣#0]\n"
               "\tLDR␣R1,␣[%[inp],␣#4]\n"
               "\tCMP␣R0,␣R1\n"
               "\tBLE␣done\n"
               "\tMOV␣R3,␣R0\n"
               "\tMOV␣R0,␣R1\n"
               "\tMOV␣R1,␣R3\n"
               "done:␣STR␣R0,␣[%[inp],␣#0]\n"
               "\tSTR␣R1,␣[%[inp],␣#4]\n"
               : [result] "=r" (res)
               : [inp] "r" (pair)
               : "r0", "r1", "r3", "cc"  );
}
```

Discussion

- `inp` needs to be in a register, because it contains the base address in a load operation (`LDR`)
- we don't use `res` in this case, but it usually needs the `"=r"` modifier and constraint
- the clobber list must name **all registers that are modified** in the code: `r0, r1, r3`
- we could pass in an immediate value `sizeof(ulong)` and use it instead of the literal `#4` to make the code less hardware-dependent

Summary

- With gcc's in-line assembler commands (`asm`) you can embed assembler code into C code.
- This avoids having to write code in separate files and then link them together.
- The assembler code can be parameterised over C variables and expressions, to simplify passing arguments.
- Care needs to be taken to define **constraints** and **modifiers** (keep data in registers or memory)
- Registers that are modified need to be explicitly identified in the "clobber list".
- It is recommended to use such in-line assembler code for CW2, where you need to develop an applicaion in C and assembler.

Sample sources: sample0.c, and sumav1_asm.c

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