Stack and subroutines

R. Ferrero, P. Bernardi

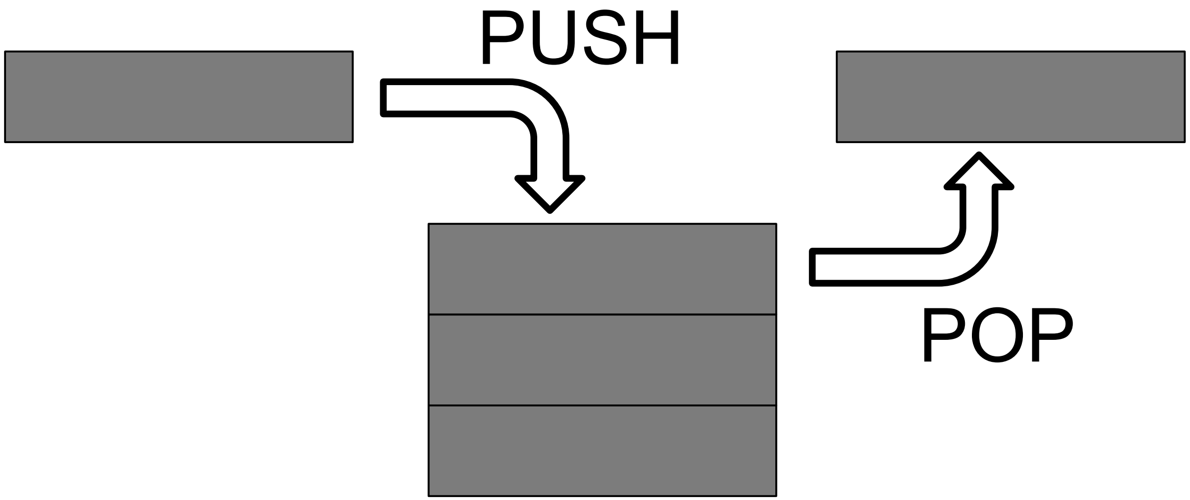
Politecnico di Torino

Dipartimento di Automatica e Informatica (DAUIN)

Torino - Italy

Stack

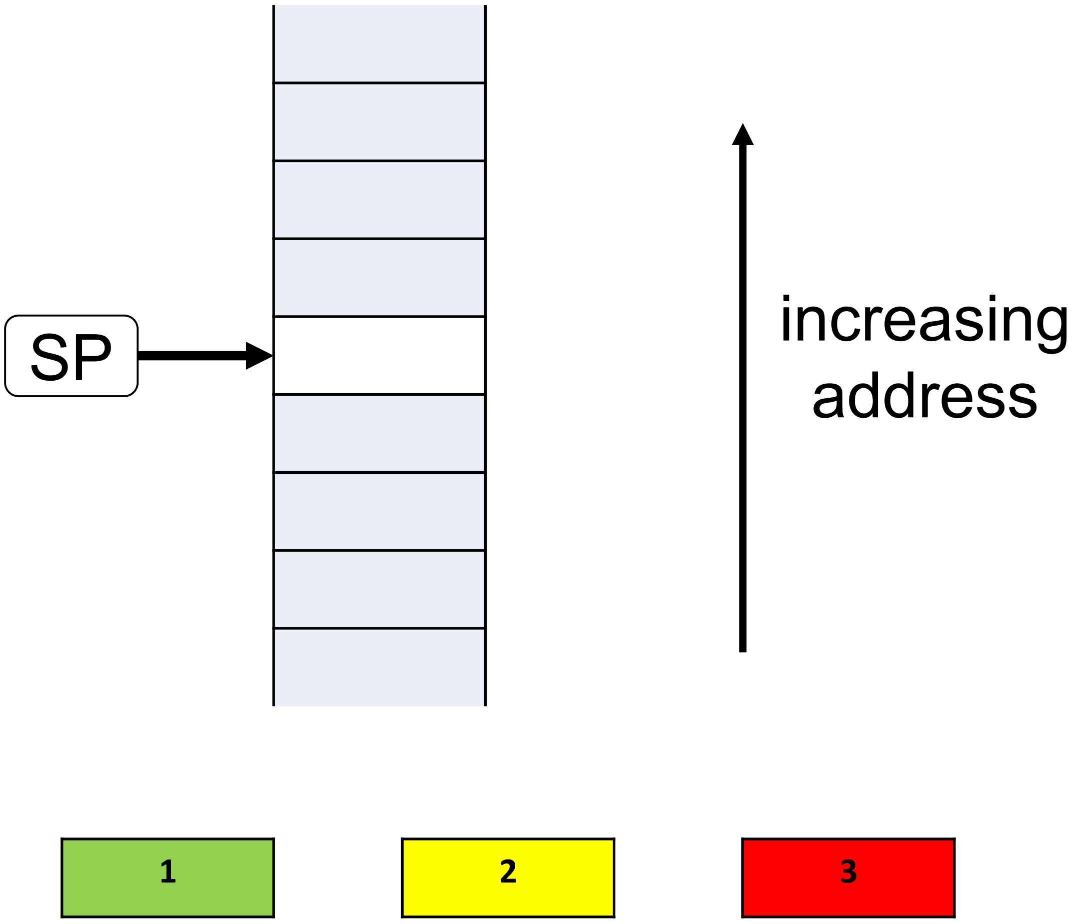
- A stack is a Last In-First Out (LIFO) queue.
- Data is pushed (written) to and popped (read) from the top of the stack.
- The stack pointer contains the address of the top of the stack.



Types of stack

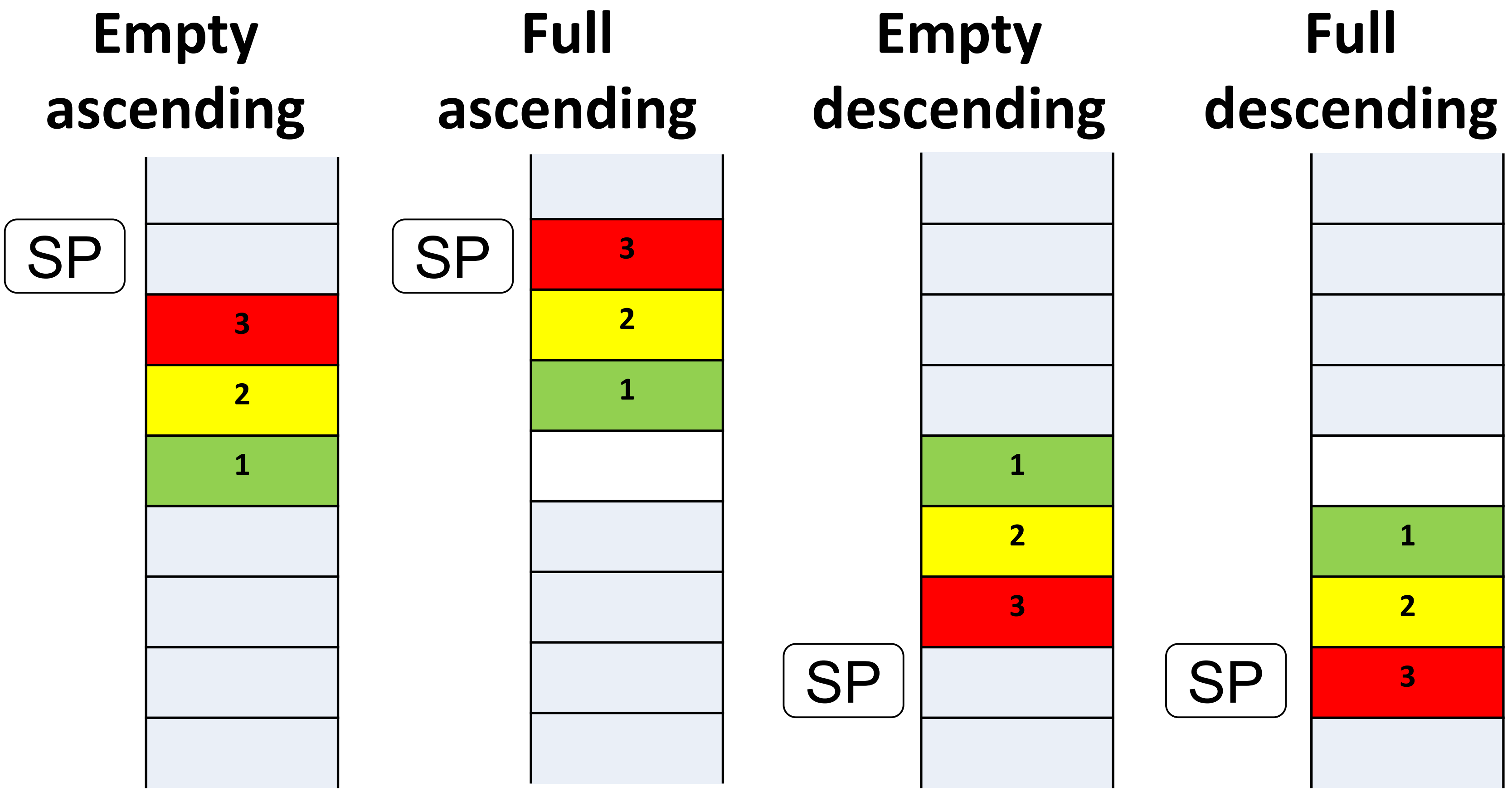
- Stack pointer update after push:
  - *descending stack*: the address of the top of the stack decreases after a push
  - *ascending stack*: the address of the top of the stack increases after a push
- Content of the entry at the top of the stack:
  - *empty stack*: the stack pointer points to the entry where new data will be pushed
  - *full stack*: the stack pointer points to the last pushed entry.

Example with PUSH: initial state

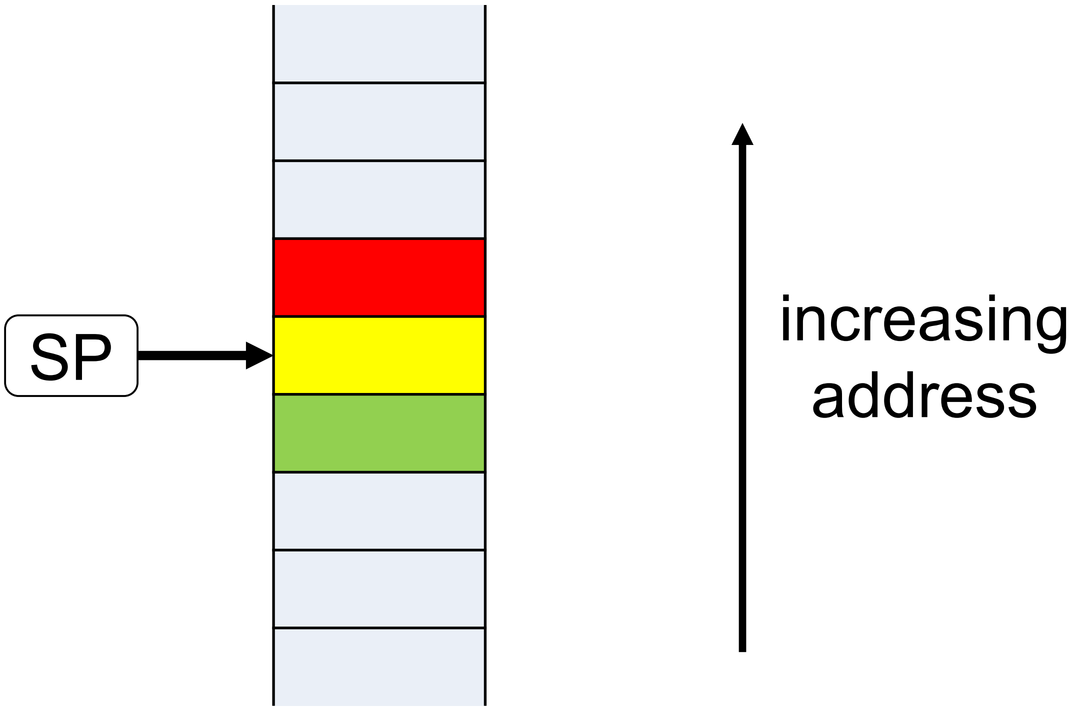


- 3 PUSH:

Example after 3 PUSH

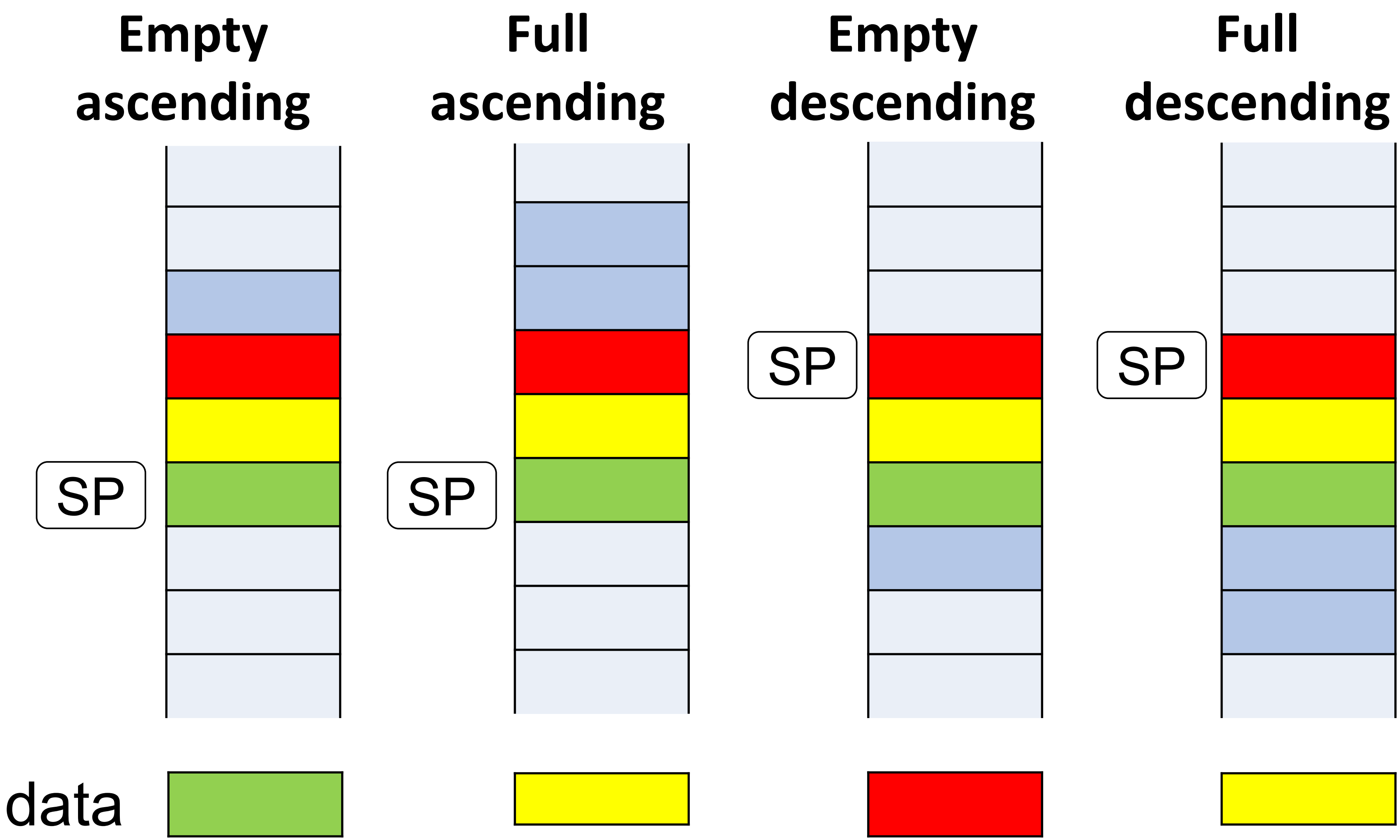


Example with POP: initial state



- 1 POP

Example after 1 POP



LDM and STM

- They transfer one or more words:

```
LDM{xx}/STM{xx} <Rn>{!}, <regList>
```

- `Rn` is the base register
- `xx` specifies the addressing mode, i.e., how and when `Rn` is updated during the instruction
- at the end of the instruction:
    - with `!`, `Rn` is set to the updated value
    - without `!`, `Rn` is set to the initial value
- `regList` is a list of registers.

List of registers

- Consecutive registers are indicated by sepa-rating the initial and final registers with a dash
- Non consecutive registers are separated with a comma.
- Example: `{r0-r4, r10, LR}` indicates `r0`, `r1`, `r2`, `r3`, `r4`, `r10`, `r14`.
- `SP` can not appear in the list.
- `PC` can appear only with `LDM` and only if `LR` is missing in the list.

Order of registers in the list

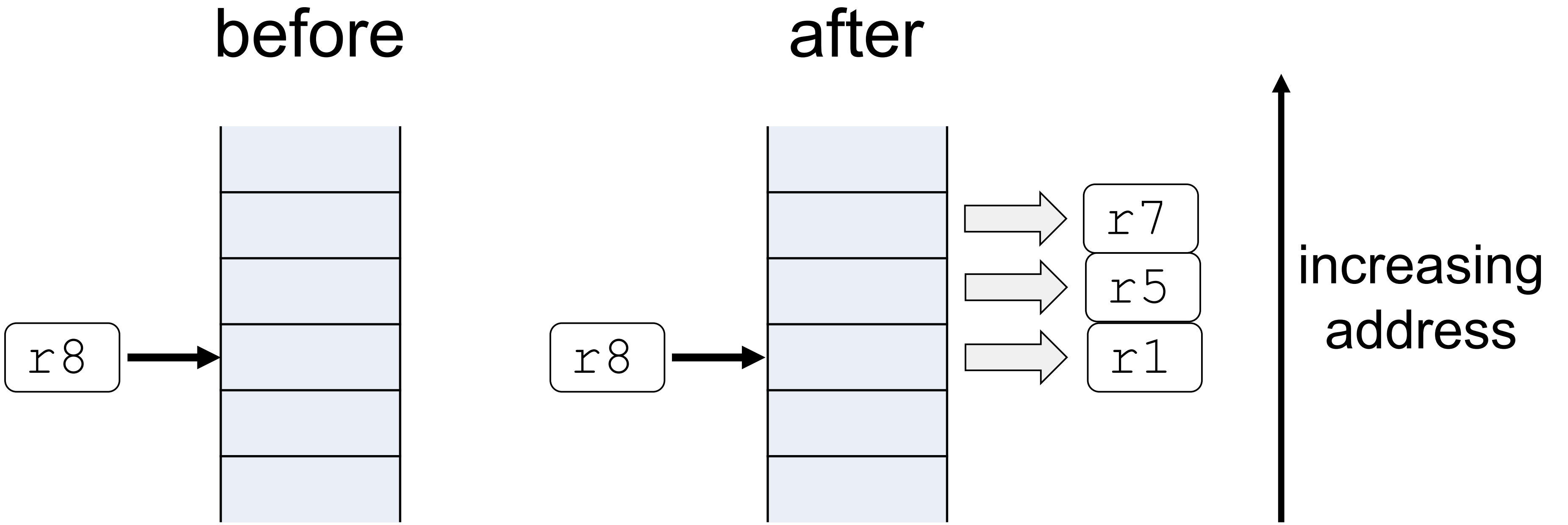
- The order of registers does not matter.
- Registers are automatically sorted in increasing order:
  - the lowest register is stored into / loaded from the lowest memory address
  - the highest register is stored into / loaded from the highest memory address
- Example: `{r8, r1, r3-r5, r14}` indicates `r1`, `r3`, `r4`, `r5`, `r8`, `r14`.

Addressing modes

- `IA`: increment after (default)
    1. memory is accessed at the address specified in the base register
    2. base register is incremented by 1 word (4 bytes)
    3. if there are other registers in the list, go to 1.
- `DB`: decrement before
    1. base register is decremented by 1 word (4 bytes)
    2. memory is accessed at the address specified in the base register
    3. if there are other registers in the list, go to 1.

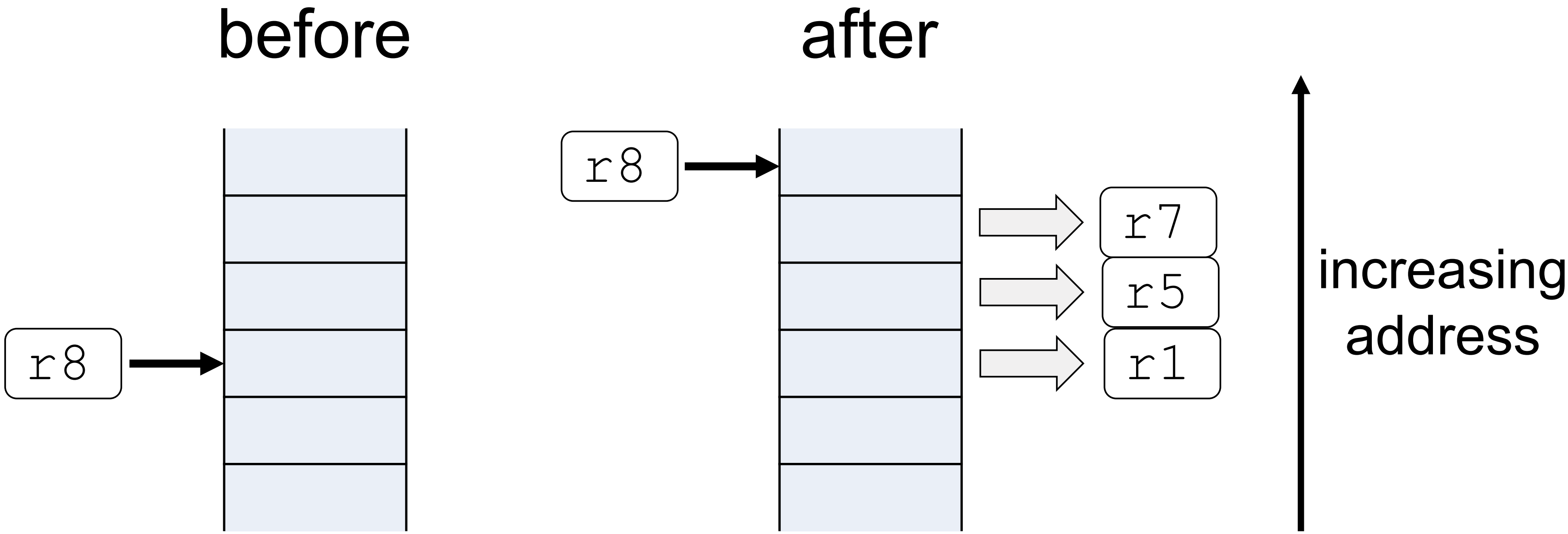
LDMIA: an example

```
LDMIA r8, {r1, r5, r7}
LDM r8, {r1, r5, r7}
```



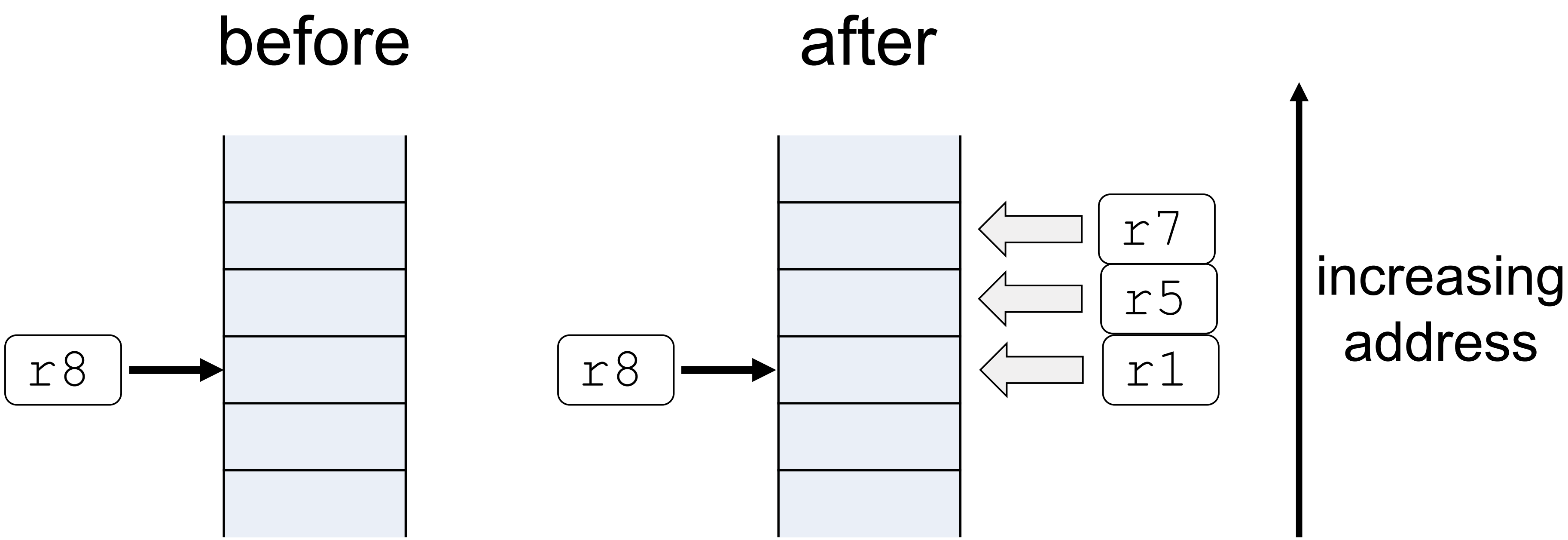
LDMIA with '!': an example

```
LDMIA r8!, {r1, r5, r7}
LDM r8!, {r1, r5, r7}
```



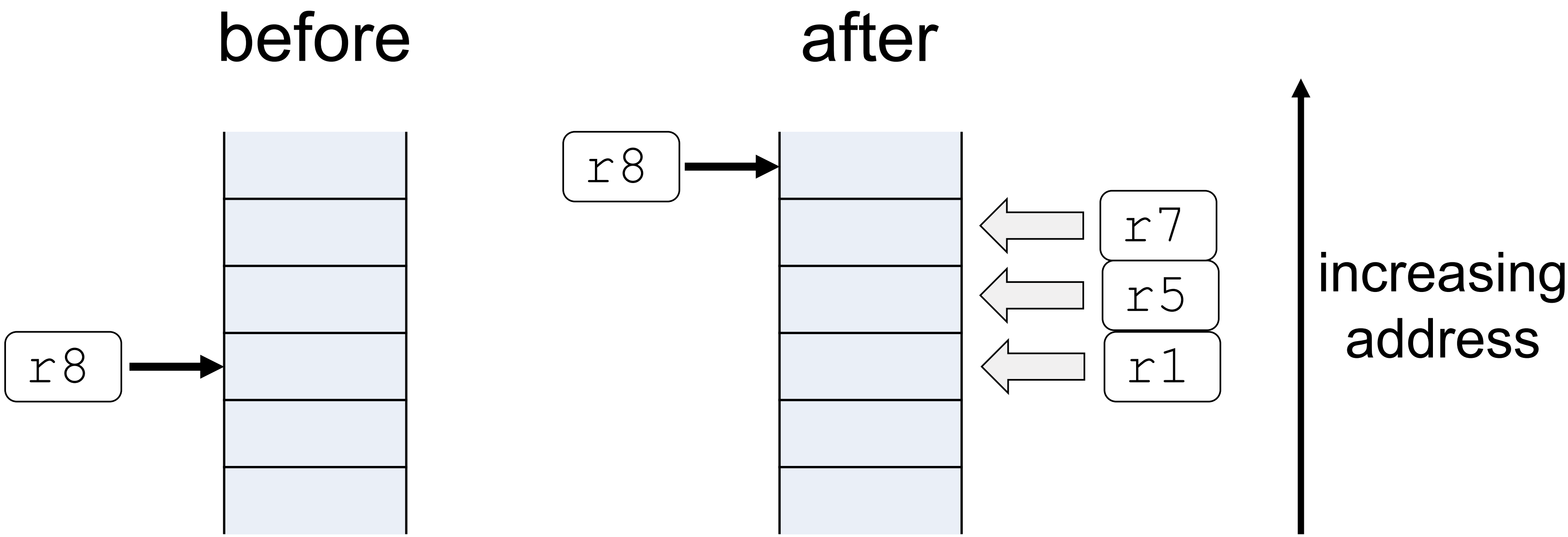
STMIA: an example

```
STMIA r8, {r1, r5, r7}
STM r8, {r1, r5, r7}
```



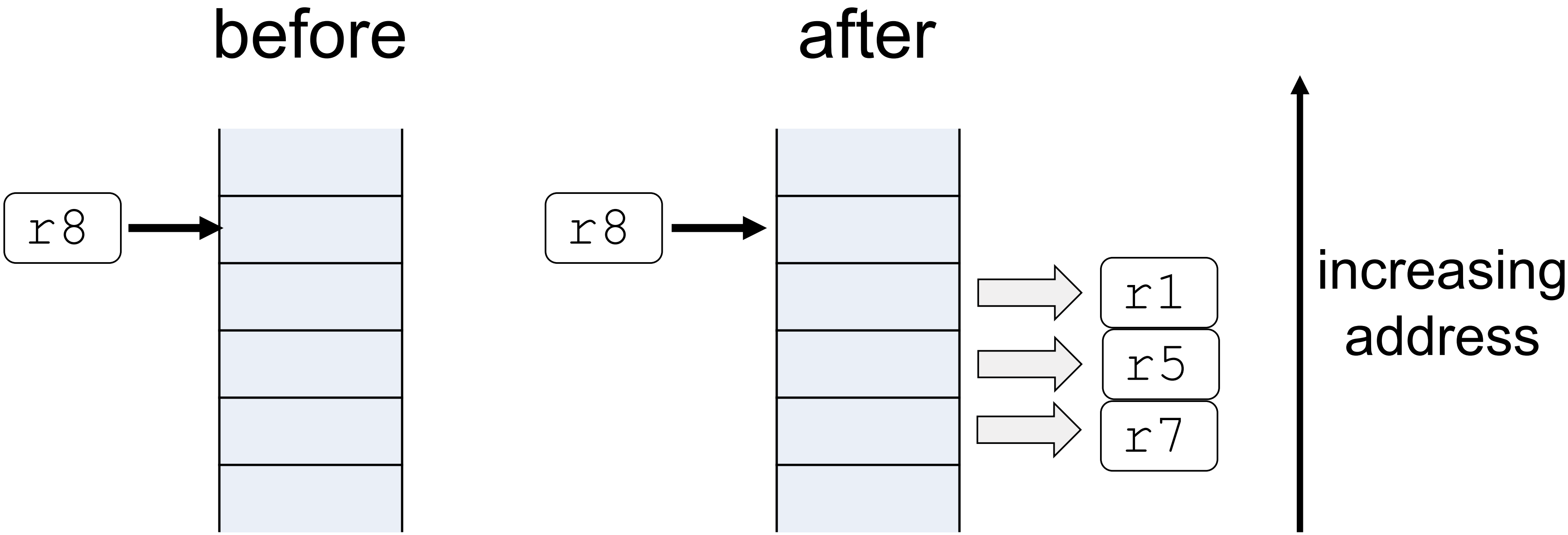
STMIA with '!': an example

```
STMIA r8!, {r1, r5, r7}
STM r8!, {r1, r5, r7}
```



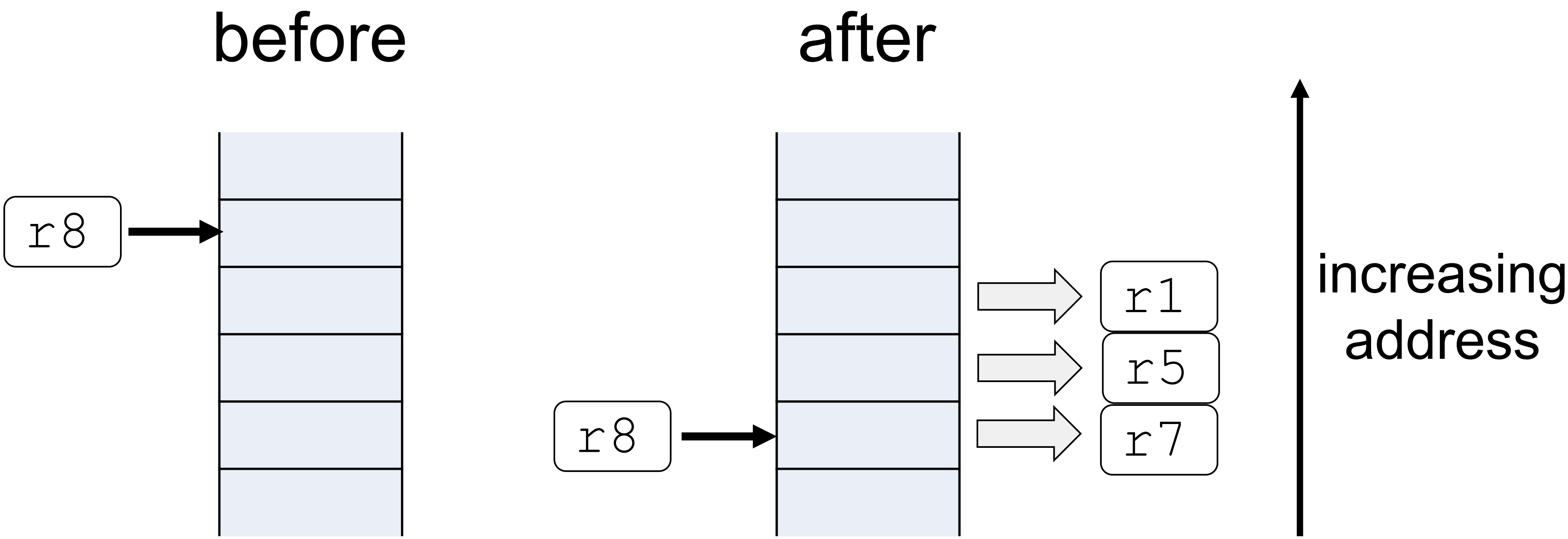
LDMDB: an example

```
LDMDB r8, {r1, r5, r7}
```



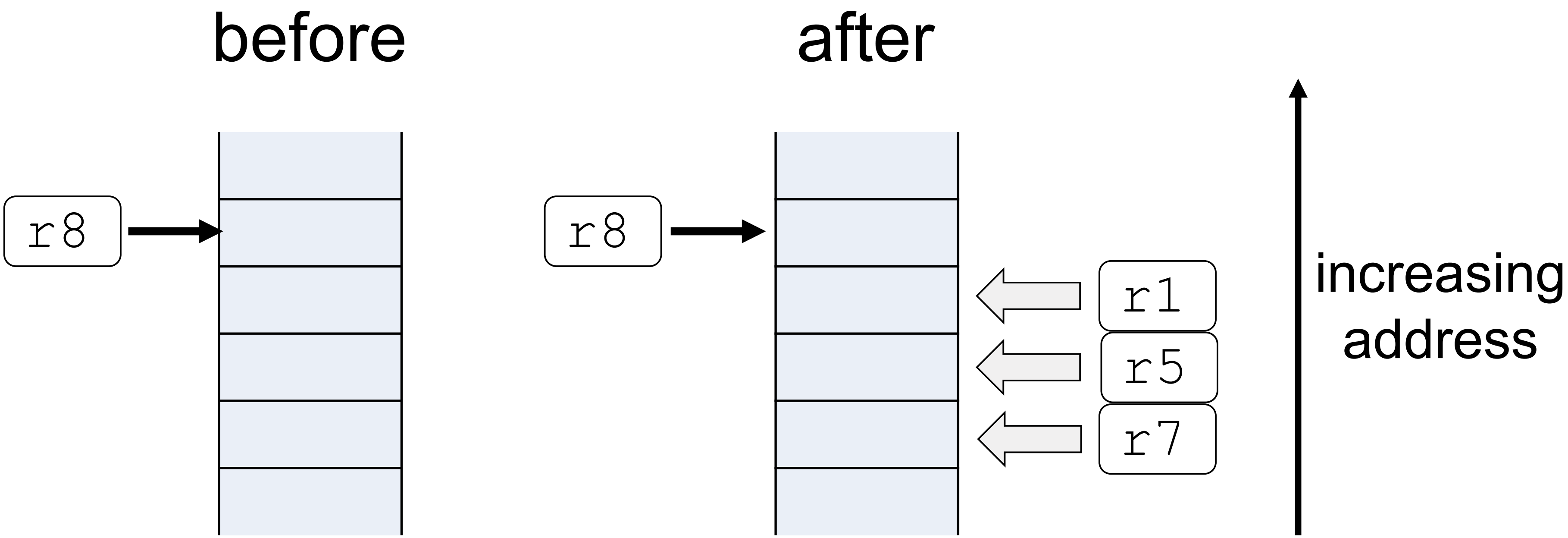
LDMDB with '!': an example

```
LDMDB r8!, {r1, r5, r7}
```



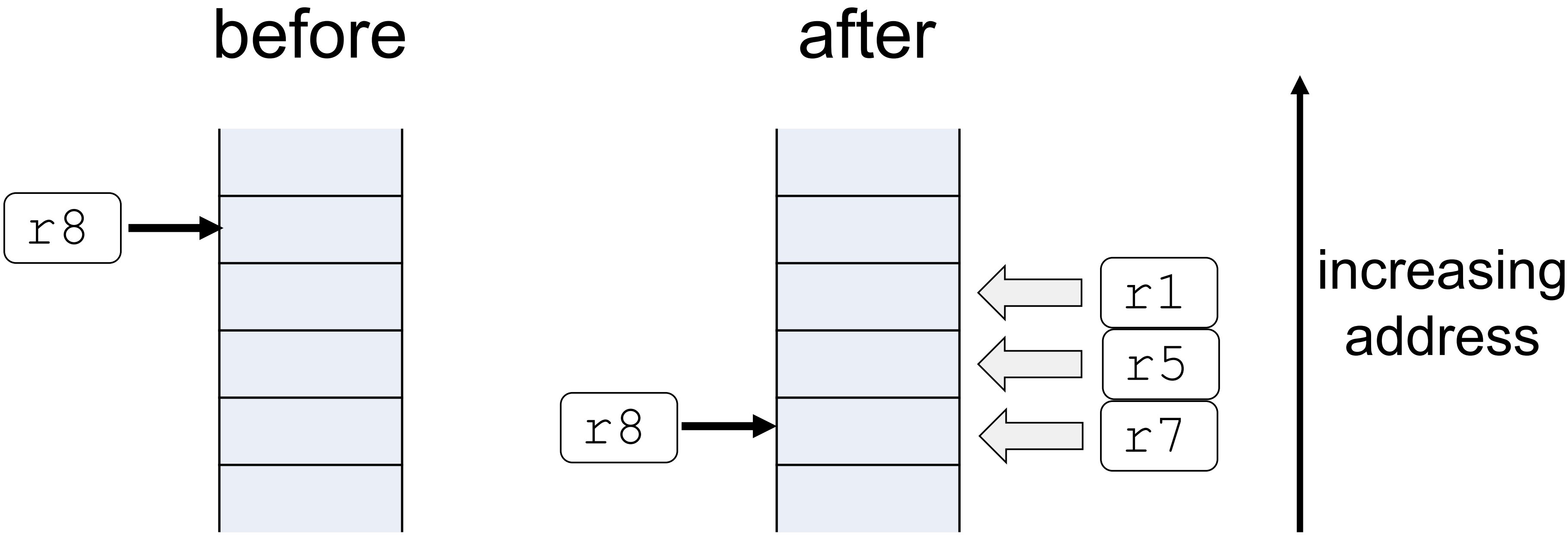
STMDB: an example

```
STMDB r8, {r1, r5, r7}
```



STMDB with '!': an example

```
STMDB r8!, {r1, r5, r7}
```



Supported types of stack

- Stack-oriented suffixes can be used instead of increment/decrement and before/after.

Stack type	PUSH	POP

Full descending	`STMDB`
	`STMFD`
		`LDM`
		`LDMIA`
		`LDMFD`

Empty ascending	`STM`
	`STMIA`
	`STMEA`
		`LDMDB`
		`LDMEA`

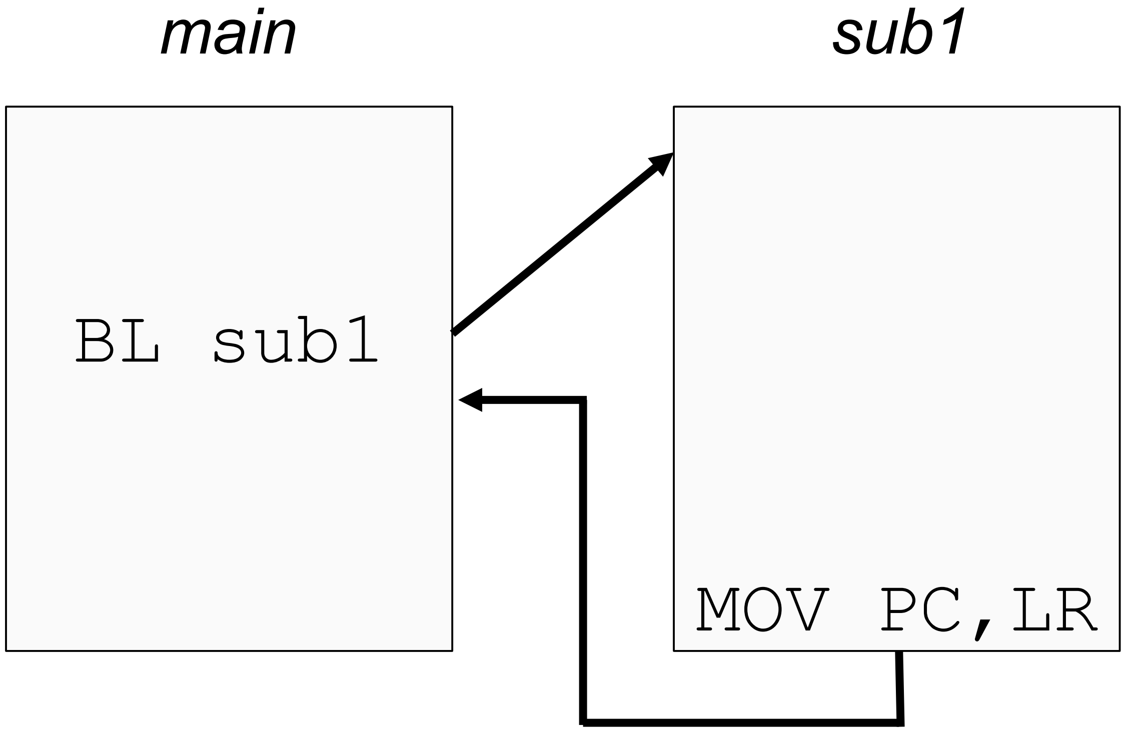
PUSH and POP

- `PUSH` and `POP` instructions facilitate the use of a full descending stack.
- `PUSH <regList>` is the same as
  `STMDB SP!, <regList>`
- `POP <regList>` is the same as
  `LDMIA SP!, <regList>`

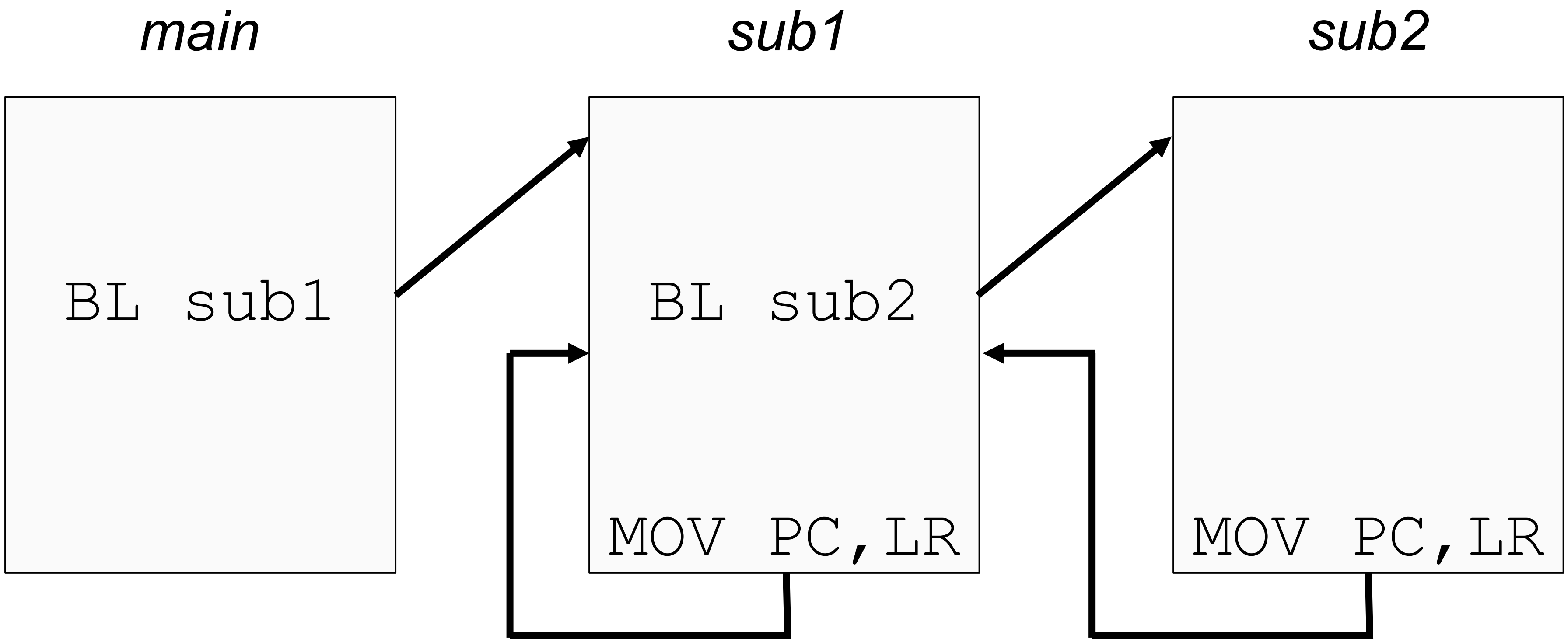
Subroutine

- A subroutine is called with `BL` and `BLX`.
- `BL <label>` and `BLX <Rn>`:
  - write the address of the next instruction to `LR`
  - write the value of `label` or `Rn` to `PC`
- A reentrant procedure ends with a branch to the address stored in `LR`.
- Optionally, the begin and end of a subroutine can be indicated with the directives `PROC`/`FUNCTION` and `ENDP`/`ENDFUNC`.

Call to subroutine



Nested calls to subroutines



- When *sub1* calls *sub2*, `LR` is overwritten.
- *sub1* is not able to return to *main*.

Nested calls to subroutines

- Besides changing `LR` when called, *sub2* may also change the value of registers used in *sub1*.
- Every subroutine should save `LR` and the other used registers as first instruction:

```
PUSH {regList, LR}
```

- At the end, the subroutine restores `PC` and the initial value of the used registers:

```
POP {regList, PC}
```

Passing parameters and result

- There are three approaches:
  - in registers
  - by reference, i.e., a register with an address in memory
  - on the stack
- Example: a main routine calls a subroutine for computing the absolute difference of two unsigned numbers.

Passing parameters in registers

```
    MOV r0, #0x34
    MOV r1, #0xA3
    BL sub1
    ; r2 contains the result
...
stop B stop
...
```

Passing parameters in registers

```
sub1 PROC
        PUSH {LR}
        CMP r0, r1
        ITE HS
        SUBHS r2, r0, r1
        SUBLO r2, r1, r0
        POP {PC}
        ENDP
```

Passing parameters by reference

```
    MOV r0, #0x34
    MOV r1, #0xA3
    LDR r3, =mySpace
    STMIA r3, {r0, r1}
    BL sub2
    LDR r2, [r3]
    ; r2 contains the result
...
stop B stop
...
```

By reference parameter

Passing parameters by reference

```
sub2 PROC
        PUSH {r2, r4, r5, LR}
        LDMIA r3, {r4, r5}
        CMP r4, r5
        ITE HS
        SUBHS r2, r4, r5
        SUBLO r2, r5, r4
        STR r2, [r3]
        POP {r2, r4, r5, PC}
        ENDP
```

Passing parameters on the stack

```
    MOV r0, #0x34
    MOV r1, #0xA3
1   PUSH {r0, r1, r2}
    BL sub3
    POP {r0, r1, r2}
    ; r2 contains the result
...
stop B stop
...
```

Prepare arguments and leave space for results

Passing parameters on the stack

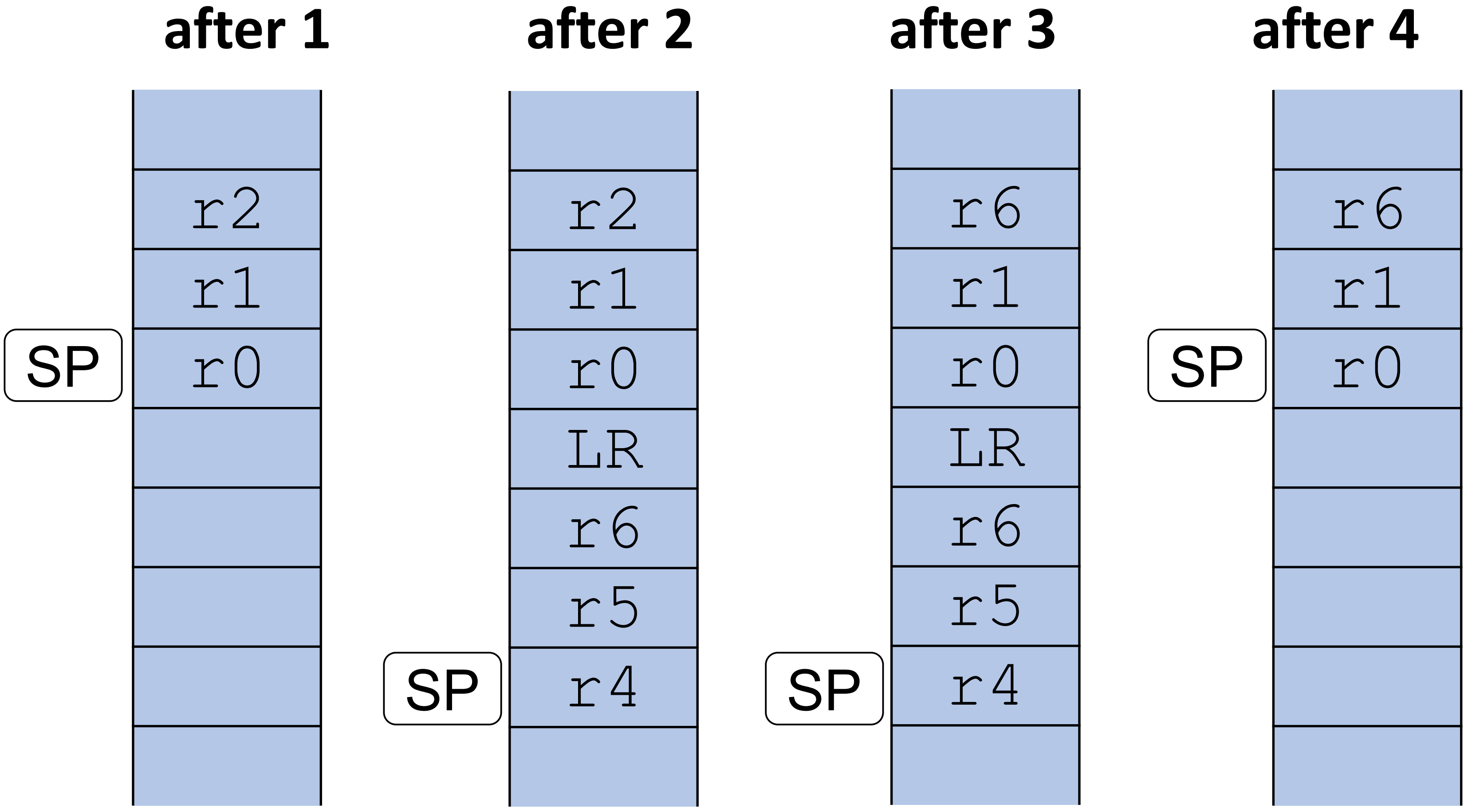
```
sub3 PROC
   2 PUSH {r6, r4, r5, LR}
     LDR r4, [sp, #16]
     LDR r5, [sp, #20]
     CMP r4, r5
     ITE HS
     SUBHS r6, r4, r5
     SUBLO r6, r5, r4
   3 STR r6, [sp, #24]
   4 POP {r6, r4, r5, PC}
     ENDP
```

Save all registers that are used to hold the values of a routine's local variables

Saves results

Restore registers content, update PC to LR to return to the caller function

Elements in the stack



ABI – Application Binary Interface

- In computer software, an application binary interface (ABI) is an interface between two binary program modules;
  - often, one of these modules is a library or operating system facility, and
  - the other is a program that is being run by a user
- A common aspect of an ABI is the calling convention, which determines how data is provided as input to or read as output from computational routines.

ABI standard for ARM

Application Binary Interface for the ARM® Architecture
The Base Standard

Document number: ARM IHI 0036B, current through ABI release 2.09
Date of Issue: 10th October 2008, reissued 30th November 2012

Abstract

This document describes the structure of the Application Binary Interface (ABI) for the ARM architecture, and links to the documents that define the base standard for the ABI for the ARM Architecture. The base standard governs inter-operation between independently generated binary files and sets standards common to ARM-based execution environments.

Keywords

ABI for the ARM architecture, ABI base standard, embedded ABI

ABI components

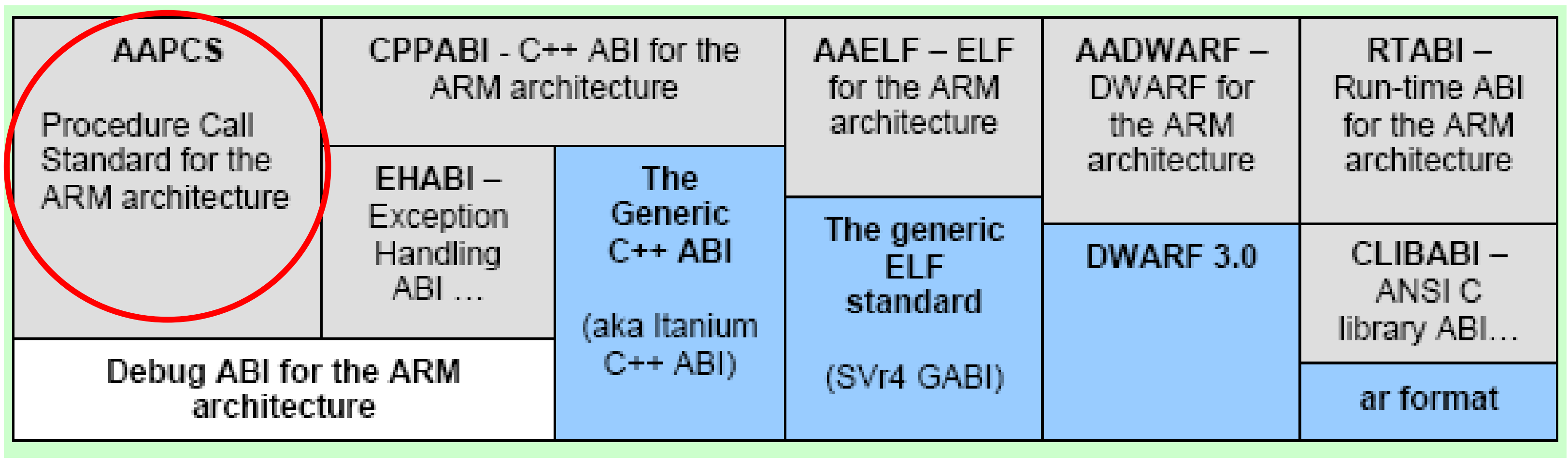
1.2 References

This document refers to the following documents.

Ref	External URL	Title
AADWARF		DWARF for the ARM Architecture
AAELF		ELF for the ARM Architecture
AAPCS		Procedure Call Standard for the ARM Architecture
ADDENDA		Addenda to, and errata in, the ABI for the ARM Architecture
BPABI		Base Platform ABI for the ARM Architecture
BSABI	*This document*	ABI for the ARM Architecture (Base Standard)
CLIBABI		C Library ABI for the ARM Architecture
CPPABI		C++ ABI for the ARM Architecture
EHABI		Exception Handling ABI for the ARM Architecture
EHEGI		Exception handling components, example implementations
RTABI		Run-time ABI for the ARM Architecture

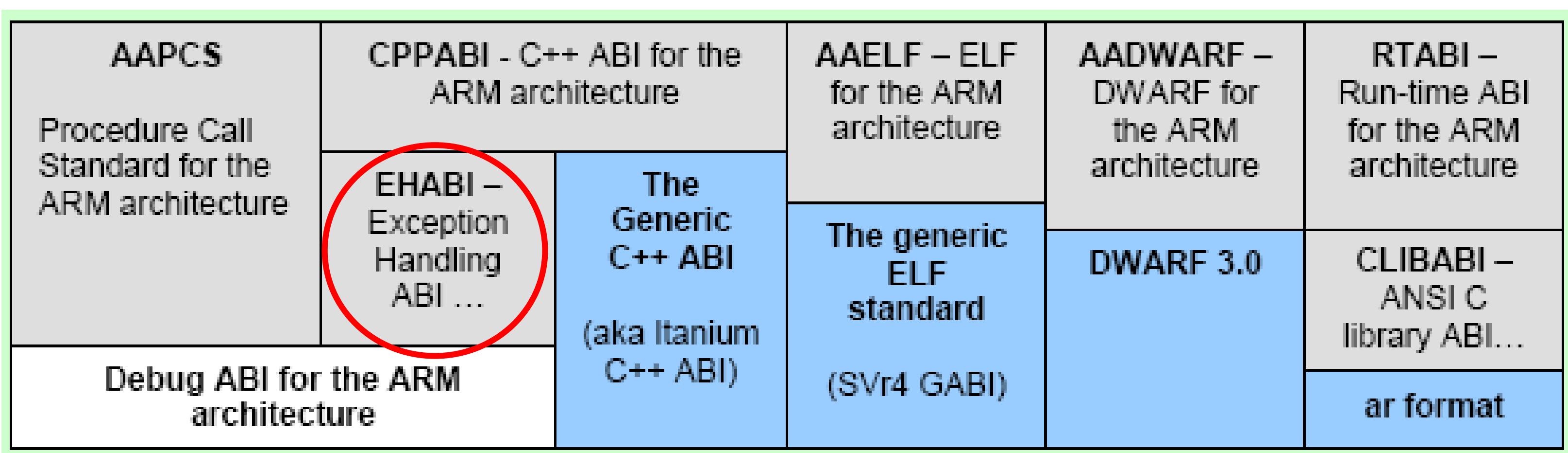
Procedure Call Standard for the ARM architecture

- The *Procedure Call Standard for the ARM architecture* [AAPCS] specifies the use of the run-time stack, and the stack invariants that must be preserved.



Exception Handling ABI for the ARM architecture

- The *Exception Handling ABI for the ARM architecture* [EHABI] specifies table-based stack unwinding that separates language-independent unwinding from language specific concerns.



ABI and other definitions in AAPCS

Term	Meaning
ABI	Application Binary Interface: 1. The specifications to which an executable must conform in order to execute in a specific execution environment. For example, the *Linux ABI for the ARM Architecture*. 2. A particular aspect of the specifications to which independently produced relocatable files must conform in order to be statically linkable and executable. For example, the *C++ ABI for the ARM Architecture*, the *Run-time ABI for the ARM Architecture*, the *C Library ABI for the ARM Architecture.*
ARM-based	… based on the ARM architecture …
EABI	An ABI suited to the needs of embedded (sometimes called *free standing*) applications.

Routine, subroutine	A fragment of program to which control can be transferred that, on completing its task, returns control to its caller at an instruction following the call. *Routine* is used for clarity where there are nested calls: a routine is the *caller* and a subroutine is the *callee*.
Procedure	A routine that returns no result value.
Function	A routine that returns a result value.
Activation stack, call-frame stack	The stack of routine activation records (call frames).
Activation record, call frame	The memory used by a routine for saving registers and holding local variables (usually allocated on a stack, once per activation of the routine).

Register	Synonym	Special	Role in the procedure call standard
r15		PC	The Program Counter.
r14		LR	The Link Register.
r13		SP	The Stack Pointer.
r12		IP	The Intra-Procedure-call scratch register.
r11	v8		Variable-register 8.
r10	v7		Variable-register 7.
r9		v6 SB TR	Platform register. The meaning of this register [illegible]ned by the platform standard.
r8	v5		Variable-register 5.
r7	v4		Variable register 4.
r6	v3		Variable register 3.
r5	v2		Variable register 2.
r4	v1		Variable register 1.
r3	a4		Argument / scratch register 4.
r2	a3		Argument / scratch register 3.
r1	a2		Argument / result / scratch register 2.
r0	a1		Argument / result / scratch register 1.

Table 2, Core registers and AAPCS usage

Can be freely used to hold local variables

If there are more than 4 formal arguments, they have to be saved in the stack

Passing arguments

- The first four registers r0-r3 (a1-a4) are used to pass argument values into a subroutine and to return a result value from a function.
  - A subroutine must preserve the contents of the registers r4-r8, r10, r11 and SP

Callee saving of caller status

- The base standard provides for passing arguments in core registers (r0-r3) and on the stack.
  - For subroutines that take a small number of parameters, only registers are used, greatly reducing the overhead of a call.

Caller saving to preserve status of non-volative register values

STACK management

- The stack implementation is *full-descending*, with the current extent of the stack held in the register SP (r13).
- The stack will, in general, have both a *base* and a *limit*
  - though in practice an application may not be able to determine the value of either.

Full descending	STMDB STMFD	LDM LDMIA LDMFD

Local variables in stack – stack frame

- It is possible to create local variables on the stack
  - in the same way we stored saved values there, by simply *subtracting the number of bytes required by each variable* from the stack pointer.
  - This does not store any data in the variables, it simply sets aside memory that we can use.