restrict, static & inline Keywords in C

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Seminar "Effiziente Programmierung in C"

December 19, 2013

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restrict

lickr.com/photos/joanet/2995263088/

restrict

- included in C99
- `restrict` is a type qualifier on pointer variables
- does not restrict anything!
- says there is no alias for an address / variable

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alias

"In computing, aliasing describes a situation in which a data location in memory can be accessed through different symbolic names in the program."

http://en.wikipedia.org/wiki/Aliasing_(computing)

Example Code

```c
void update(int *a, int *b, int *c)
{
    *a += *c;
    *b += *c;
}
```

Example Code

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```c
void update_restrict(int *restrict a, int *restrict b,
    int *restrict c)
{
    *a += *c;
    *b += *c;
}
```

Example Code

```
1  int main(int argc, char** argv)
2  {
3      int a = 1; int b = 2; int c = 3;
4
5      update(&a, &b, &c);
6      printf("Expected Result: %d %d\n", a, b);
7
8      a = 1; b = 2; c = 3; // reset values
9
10     update_restrict(&a, &b, &c);
11     printf("Actual Result:   %d %d\n", a, b);
12
13     return 0;
14 }
```

```
1  void update(int *a, int *b, int *c)
2  {
3      *a += *c;
4      *b += *c;
5  }
```

Example Code

```
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    update(&a, &b, &c);
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    a = 1; b = 2; c = 3; // reset values

    update_restrict(&a, &b, &c);
    printf("Actual Result:   %d %d\n", a, b);

    return 0;
}
```
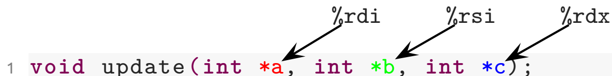

```
Expected Result: 4 5
Actual Result:   4 5
```

How It Works

```c
void update(int *a, int *b, int *c);
```

How It Works




```
1 void update(int *a, int *b, int *c);
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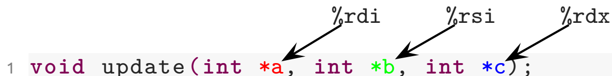
```
1 update:
2     movq    (%rdx), %rax
3     addq    %rax,   (%rdi)
4     movq    (%rdx), %rax
5     addq    %rax,   (%rsi)
6     ret
```

var	reg	val	*val
a	%rdi	0x123	1
b	%rsi	0x124	2
c	%rdx	0x125	3
-	%rax		-

How It Works

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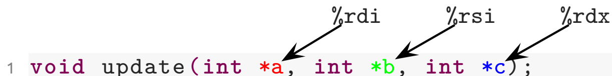


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```
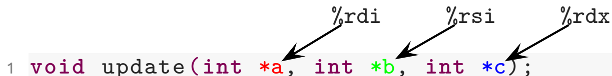

var	reg	val	*val
a	%rdi	0x123	4
b	%rsi	0x124	2
c	%rdx	0x125	3
-	%rax	3	-

How It Works

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```

var	reg	val	*val
a	%rdi	0x123	4
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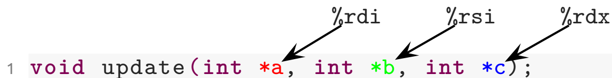
c	%rdx	0x125	3
–	%rax	3	–

How It Works

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6     ret
```
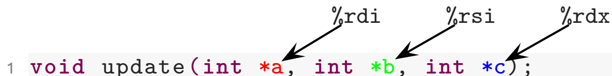

var	reg	val	*val
a	%rdi	0x123	4
b	%rsi	0x124	5
c	%rdx	0x125	3
-	%rax	3	-

How It Works




```
1 void update(int *a, int *b, int *c);
```

```
1 void update_restrict(int *restrict a, int *restrict
      b, int *restrict c);
```

```
1 update:
2     movq    (%rdx), %rax
3     addq    %rax,   (%rdi)
4     movq    (%rdx), %rax
5     addq    %rax,   (%rsi)
6     ret
```

```
1 update_restrict:
2     movq    (%rdx), %rax
3     addq    %rax,   (%rdi)
4     addq    %rax,   (%rsi)
5     ret
```

Passing Incorrect Parameters

```c
int main(int argc, char** argv)
{
    int a = 1;
    int b = 2;

    update(&a, &b, &a);
    printf("Expected Result: %d %d\n", a, b);

    a = 1; b = 2; // reset values

    update_restrict(&a, &b, &a);
    printf("Actual Result:   %d %d\n", a, b);
}
```

```c
void update(int *a, int *b, int *c)
{
    *a += *c;
    *b += *c;
}
```

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int main(int argc, char** argv)
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    a = 1; b = 2; // reset values

    update_restrict(&a, &b, &a);
    printf("Actual Result:   %d %d\n", a, b);
}
```

```
Expected Result: 2 4
Actual Result:   2 3
```

Passing Incorrect Parameters

```c
void update_restrict(int *restrict a, int *restrict
    b, int *restrict c);
```

```asm
update_restrict:
    movq    (%rdx), %rax
    addq    %rax,   (%rdi)
    addq    %rax,   (%rsi)
    ret
```

var	reg	val	*val
a	%rdi	0x123	1
b	%rsi	0x124	2
c	%rdx	0x123	1
–	%rax		–

Passing Incorrect Parameters

```
1 void update_restrict(int *restrict a, int *restrict
      b, int *restrict c);
```

```
1 update_restrict:
2     movq    (%rdx), %rax
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5     ret
```

var	reg	val	*val
a	%rdi	0x123	1
b	%rsi	0x124	2
c	%rdx	0x123	1
–	%rax	1	–

Passing Incorrect Parameters

```c
void update_restrict(int *restrict a, int *restrict
    b, int *restrict c);
```

```asm
update_restrict:
    movq    (%rdx), %rax
    addq    %rax,   (%rdi)
    addq    %rax,   (%rsi)
    ret
```

var	reg	val	*val
a	%rdi	0x123	2
b	%rsi	0x124	2
c	%rdx	0x123	2
–	%rax	1	–

Passing Incorrect Parameters

```c
void update_restrict(int *restrict a, int *restrict
    b, int *restrict c);
```

```
update_restrict:
    movq    (%rdx), %rax
    addq    %rax,   (%rdi)
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    ret
```

var	reg	val	*val
a	%rdi	0x123	2
b	%rsi	0x124	3
c	%rdx	0x123	2
-	%rax	1	-

Performance

```c
void update(int *a, int *b, int *c)
{
    for(i = 0; i < iterations; i++)
    {
        *a += *c;
        *b += *c;
    }
}
```

- 100.000.000.000 Iterations
- without restrict: 249.086421s
- with restrict: 83.690911s

⇒ Performance Benefit: 2,98x faster

Why should I use it?

- Better Performance :)
- `restrict` is recommended to be used in every new code
- You don't need to, if you don't want to!
- (However, be careful!)

static
http://www.flickr.com/photos/38102502@N07/3757737766/in/photolist-6J4owb

Translation Unit (nota bene)

- is the output of the preprocessor / input to the compiler
- is a single .c file after preprocessing
  - header files have been included
  - #ifdef's have been evaluated
  - macros have been expanded
- basically, same translation unit means the same file

static

- used in variable and function defintions
- can be applied on
  1. global variables and functions
  2. variable definitions inside a block

Static Functions and (global) Variables

- static functions and variables are only visible to the current translation unit

```
1 static void static_function();
2 static int c = 0;
3
4 static void static_function()
5 {
6     printf("this is a static function, which can't be
          called from another file...\n");
7 }
```

Static Functions and (global) Variables

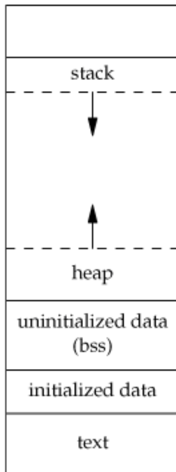
- static functions and variables are only visible to the current translation unit

```
1 static void static_function();
2 static int c = 0;
3
4 static void static_function()
5 {
6     printf("this is a static function, which can't be
          called from another file...\n");
7 }
```

+ encapsulate your private functions
+ provides access control

Static Variables (inside a block)

- initialized on compile time
- with initial value
  $\Rightarrow$ stored in data area
- without initial value (or 0)
  $\Rightarrow$ stored in bss area
- variable keeps state
  between invocations



(http://www.cs.bgu.ac.il/~caspl122/wiki.files/lab2/ch07lev1sec6/ch07lev1sec6.html)

Static Variables (inside a block): Example

```c
void static_variable()
{
    int a = 0;
    static int b = 0;

    a++;
    b++;

    printf("static variable: a=%d, b=%d\n", a, b);
}
```

Static Variables (inside a block): Example

```
 1 void static_variable()
 2 {
 3     int a = 0;
 4     static int b = 0;
 5 
 6     a++;
 7     b++;
 8 
 9     printf("static variable: a=%d, b=%d\n", a, b);
10 }
```

+ keeps state between invocations
− not thread-safe

inline
http://www.flickr.com/photos/joanet/2995263088/

inline

- included in C99
- alternative to macros
- hint to compiler, to embed function body

Example

```c
inline static int add(int s1, int s2)
{
    return s1 + s2;
}

int some_function(int a, int b)
{
    return add(a, b);
}
```

$\Rightarrow$ will be substituted to

```c
int some_function(int a, int b)
{
    return a + b;
}
```

Example: Assembler

```
add:
    leal    (%rdi,%rsi), %eax
    ret
some_function:
    call    add_inline
    rep ret
```

$\Rightarrow$ will be substituted to

```
some_function:
    leal    (%rdi,%rsi), %eax
    ret
```

inline

- can be combined with `static`
- inline functions can be called from other translation units when defined in header
- `gcc` substitutes only inline function in the same translation unit

Limitations

- Recursive Functions
- inline function with external linkage shall not use private objects (no problem with `gcc`)

Performance

```
1 for(i = 0; i < iterations; i++)
2 {
3     a = add(a, b);
4 }
```

- measured with simple addition-function (like above)
- `100.000.000.000` Iterations
- separate call: `67.553960s`
- inlined: `22.290012s`

⇒ Performance Benefit: 3,03x faster

The Compiler is smarter than you!

the compiler...

- can detect inlinable function without extra hint
- can ignore inline hint

The Compiler is smarter than you!

the compiler...

- can detect inlinable function without extra hint
- can ignore inline hint

but you can force the compiler to do or not to do inlining...!
e.g. for gcc:

```
inline __attribute__((always_inline)) int
    inline_function(int a, int b);
inline __attribute__((noinline)) int no_inline_function(
    int a, int b);
```

Should I use inline?

+ can save extra function call
+ may improve instruction cache performance
+ can make other optimizations possible
− may increase final program size

  ⇒ it may be worth doing

- (but today the compiler often does this job for you)

Summary

- restrict
  - hint to the compiler that there is no alias for a variable
  - helps to increase performance
- static
  - access control for private variables and functions
  - static variables inside blocks
- inline
  - similar to marcos
  - hint to the compiler to substitute function calls with its body
  - helps to increase performance

Questions?

Sources

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- Jürgen Wolf: C von A bis Z (3rd edition, 2009)
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- `http://cellperformance.beyond3d.com/articles/2006/05/demystifying-the-restrict-keyword.html` (November 2013)
- `http://stackoverflow.com/questions/572547/what-does-static-mean-in-a-c-program` (November 2013)
- `http://www.greenend.org.uk/rjk/tech/inline.html` (November 2013)
- `http://en.wikipedia.org/wiki/Inline_expansion` (November 2013)
- `http://www.cs.bgu.ac.il/~caspl122/wiki.files/lab2/ch07lev1sec6/ch07lev1sec6.html` (December 2013)

Thank you for your attention!

http://www.fotocommunity.com/pc/pc/display/29036692