Perses: Syntax-Guided Program Reduction

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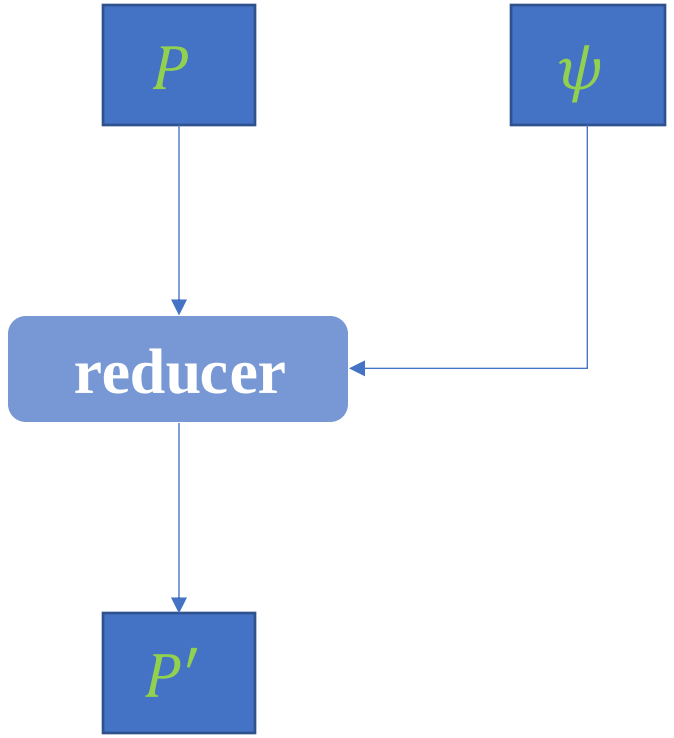
program reduction

Input:

- P: a program
- ψ: a property, and $\psi(P)$



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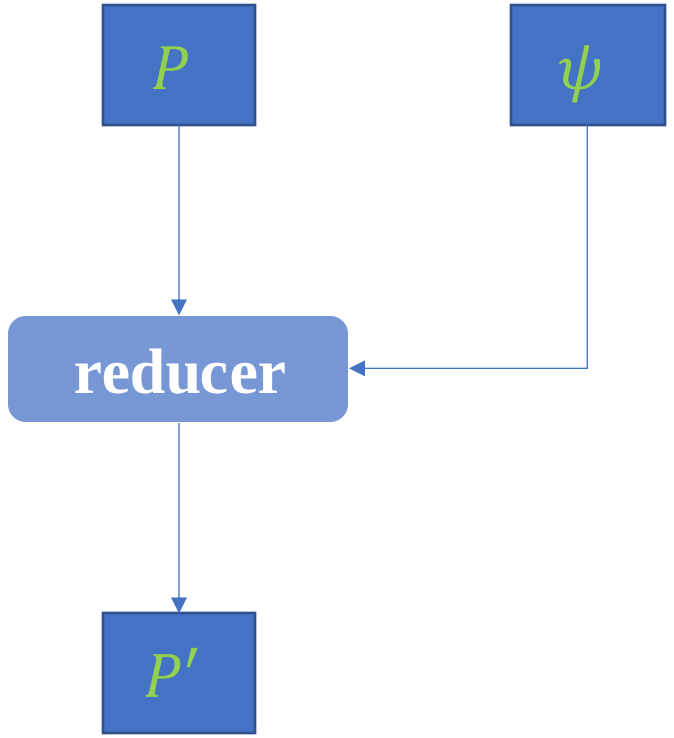

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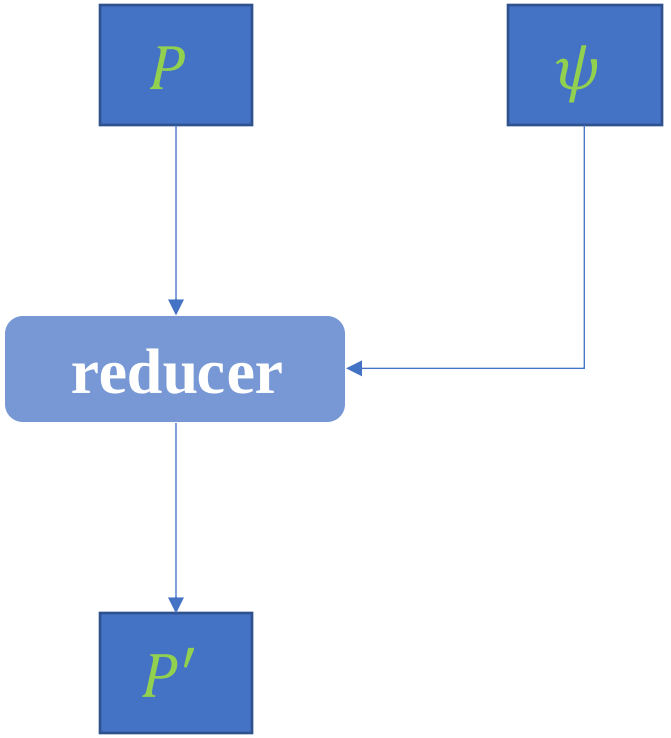

program reduction

specialized test input **minimization**

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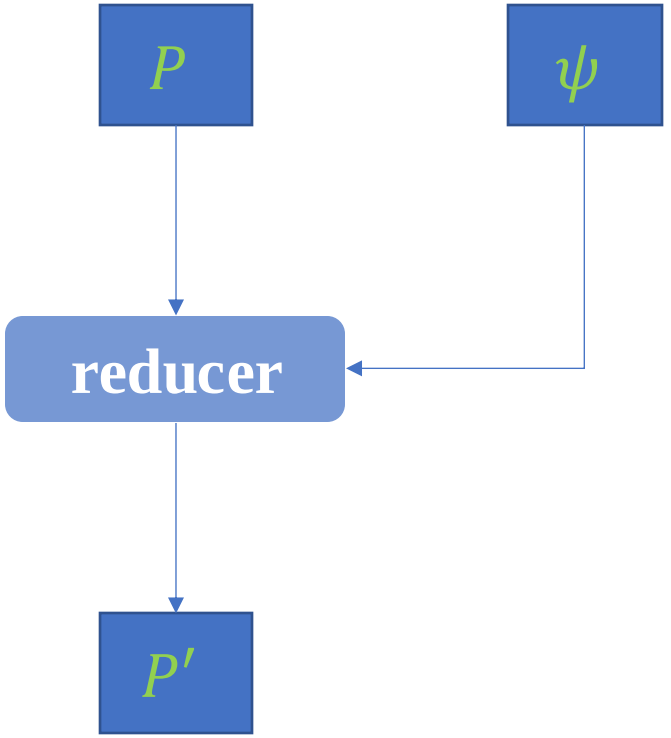

program reduction – an **important** problem

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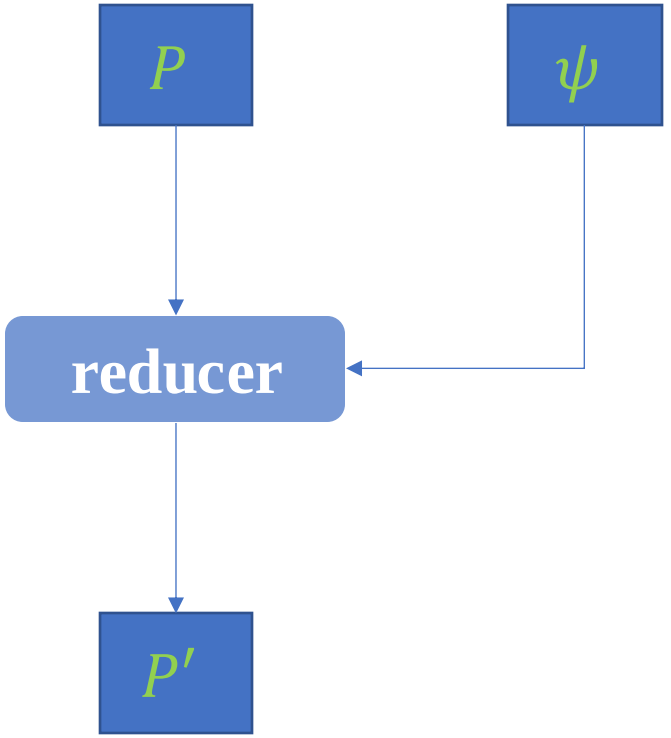

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- static analyses
  - ❖ Frama-C, Soot, Wala

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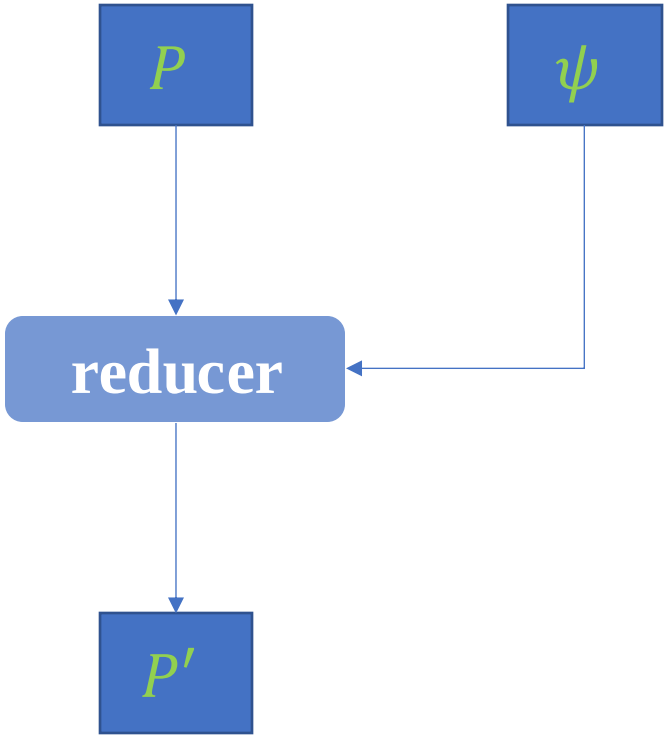

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- static analyses
  - ❖ Frama-C, Soot, Wala
- refactoring engines
  - ❖ Eclipse, IntelliJ, Netbeans

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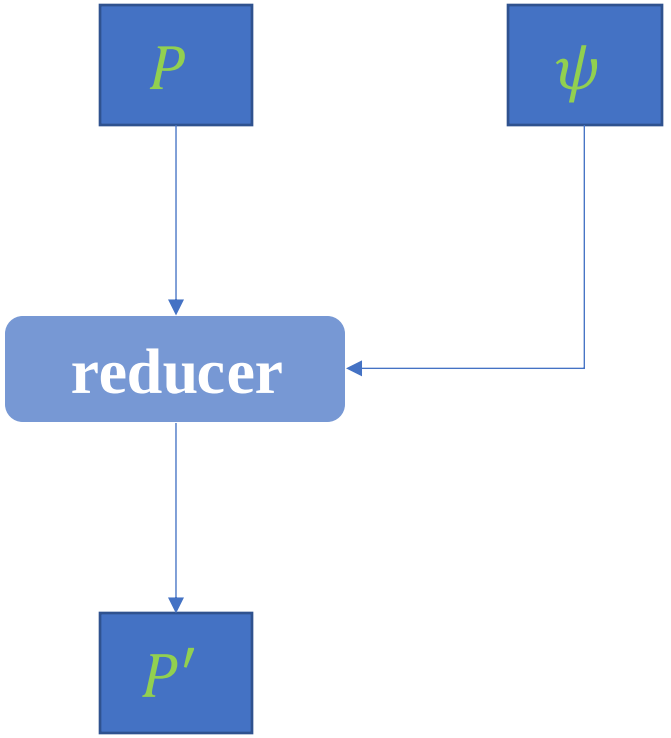

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- static analyses
  - ❖ Frama-C, Soot, Wala
- refactoring engines
  - ❖ Eclipse, IntelliJ, Netbeans
- compilers
  - ❖ **GCC** (100k+ bugs), **LLVM** (50k+ bugs), **JVM, V8**

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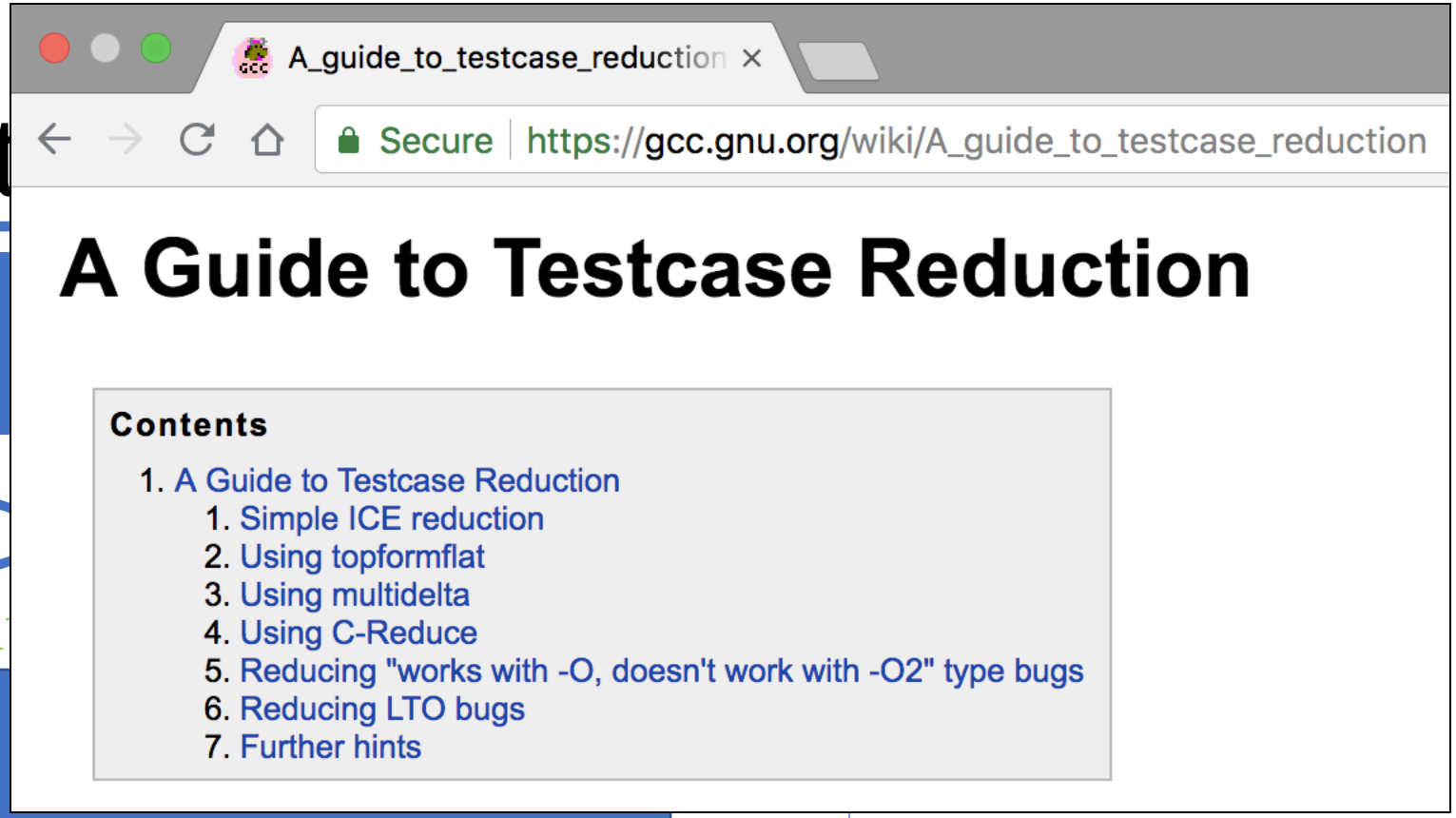

P'

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- compilers
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an example

P

```c
int main() {
 int a = 1;
 if (a) {
   printf("%d\n", a);
   printf("Hello ");
   printf("world!\n");
   printf("End\n");
 }
 return 0;
}
```

```
$ gcc t.c ; ./a.out
1
Hello world!
End
```

an example

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Hello world!
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property: ψ

print “**Hello world!**”

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property: ψ

print "**Hello world!**"

ideal result

```c
int main() {
 printf("Hello ");
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 return 0;
}
```

```
$ gcc t.c ; ./a.out
Hello world!
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state-of-the-art

- DD: Delta Debugging
  - binary search (delete lines each time and check ψ)
  - generate many **syntactically invalid** variants

ideal result

```
int main() {
 printf("Hello ");
 printf("world!\n");
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}
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DD & HDD

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 1: int main() {
 2:   int a = 1;
 3:   if (a) {
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 8:   }
 9:   return 0;
10: }
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state-of-the-art

- DD: Delta Debugging
  - binary search (delete lines each time and check ψ)
  - generate many **syntactically invalid** variants
- HDD: Hierarchical Delta Debugging
  - parse a program into a tree
  - breadth-first search and apply DD on each level
  - better at program reduction
  - generate many **syntactically invalid** variants

ideal result

```
int main() {
 printf("Hello ");
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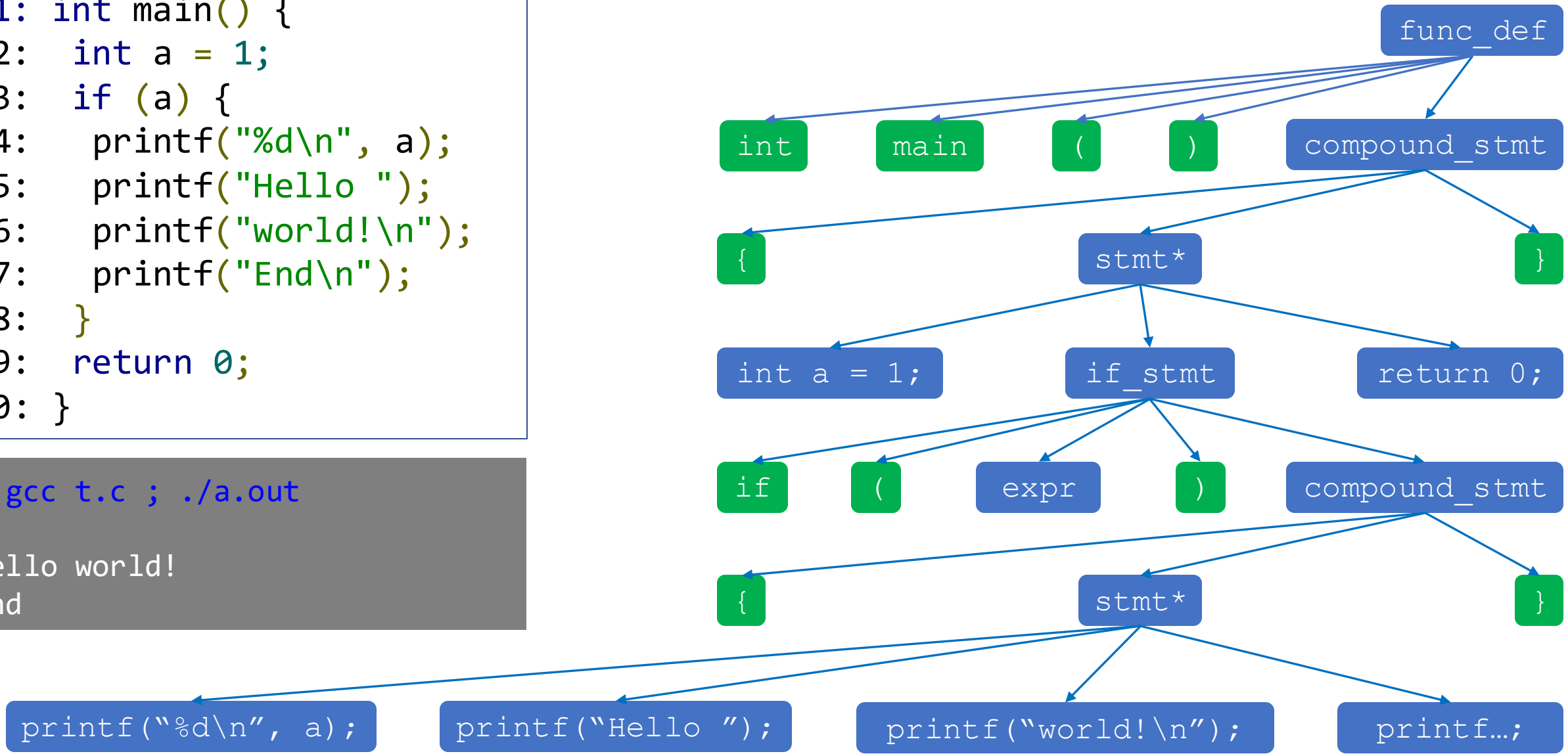
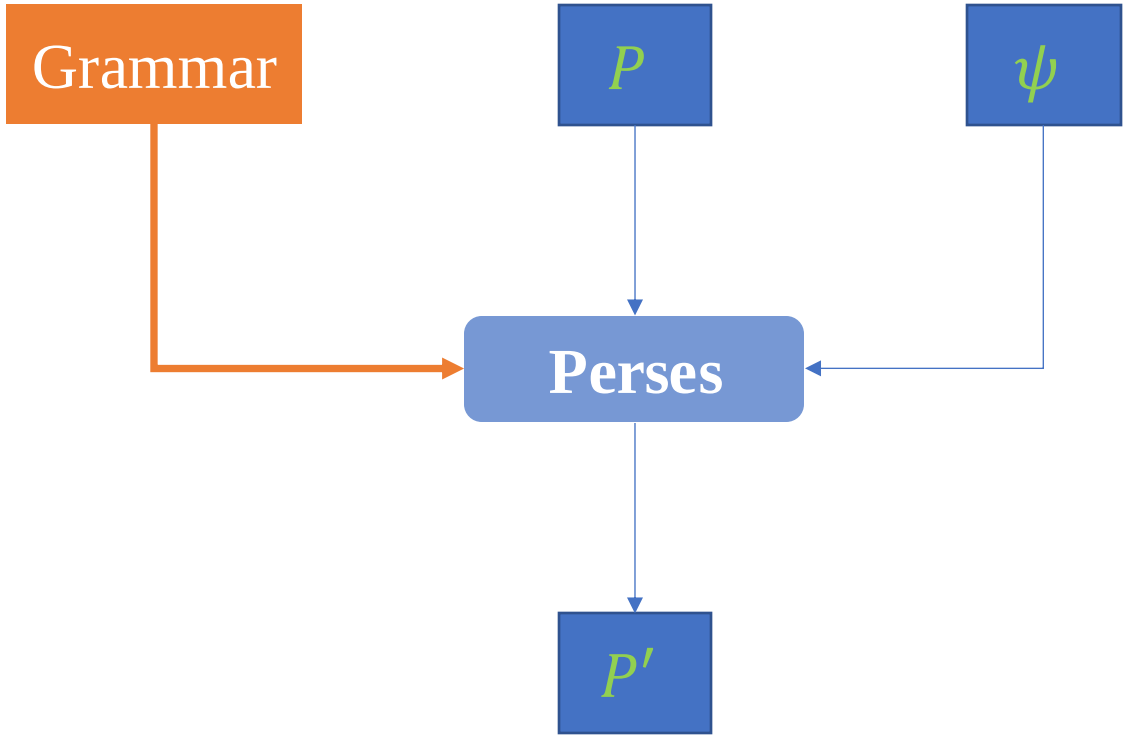


Perses: fully syntax-guided



Perses: fully syntax-guided

- Avoid generating **syntactically invalid** variants

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```
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<compound_stmt> ::= ‘{’ <stmt_star> ‘}’
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  - Most symbols are NOT removable
    - e.g., all symbols in `<func_def>`

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Perses: fully syntax-guided

- Avoid generating **syntactically invalid** variants
  - Most symbols are NOT removable
    - e.g., all symbols in `<func_def>`
  - Except symbols that are quantified by `*`, `+` and `?`
    - e.g., `printf` statements in body of `if` are removable

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Perses: fully syntax-guided

- Avoid generating **syntactically invalid** variants
- Enable more program transformations
  - e.g., replace with a **syntax-compatible** descendant

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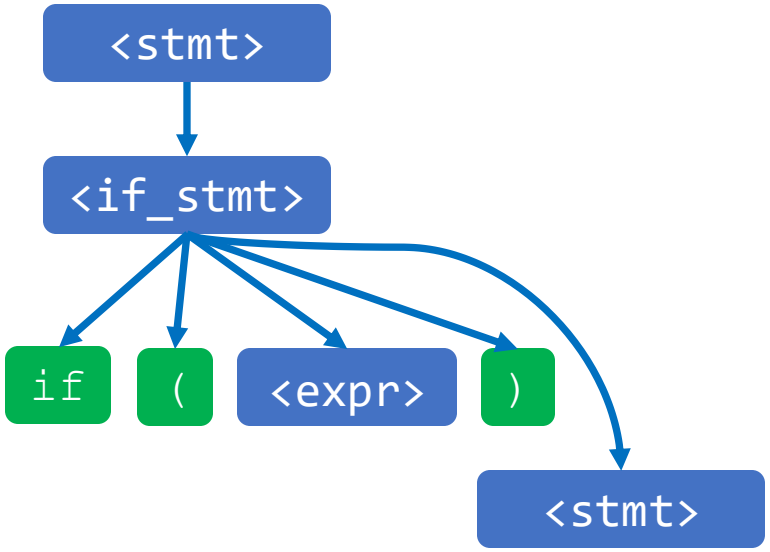


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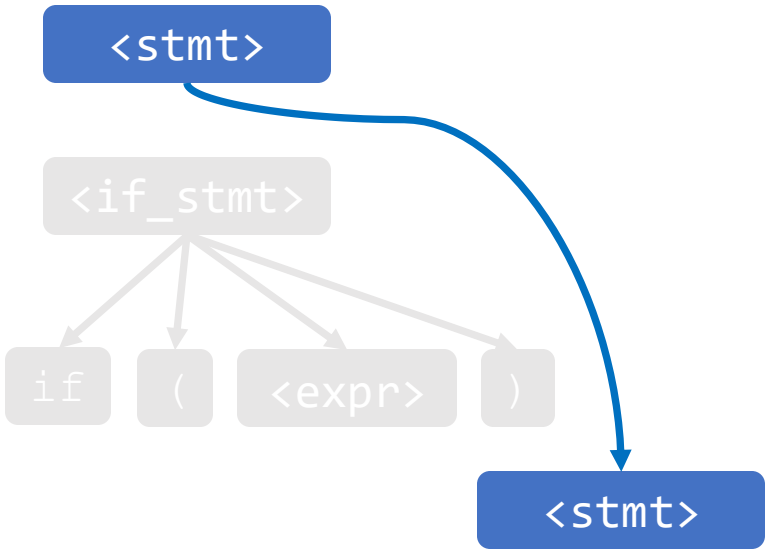


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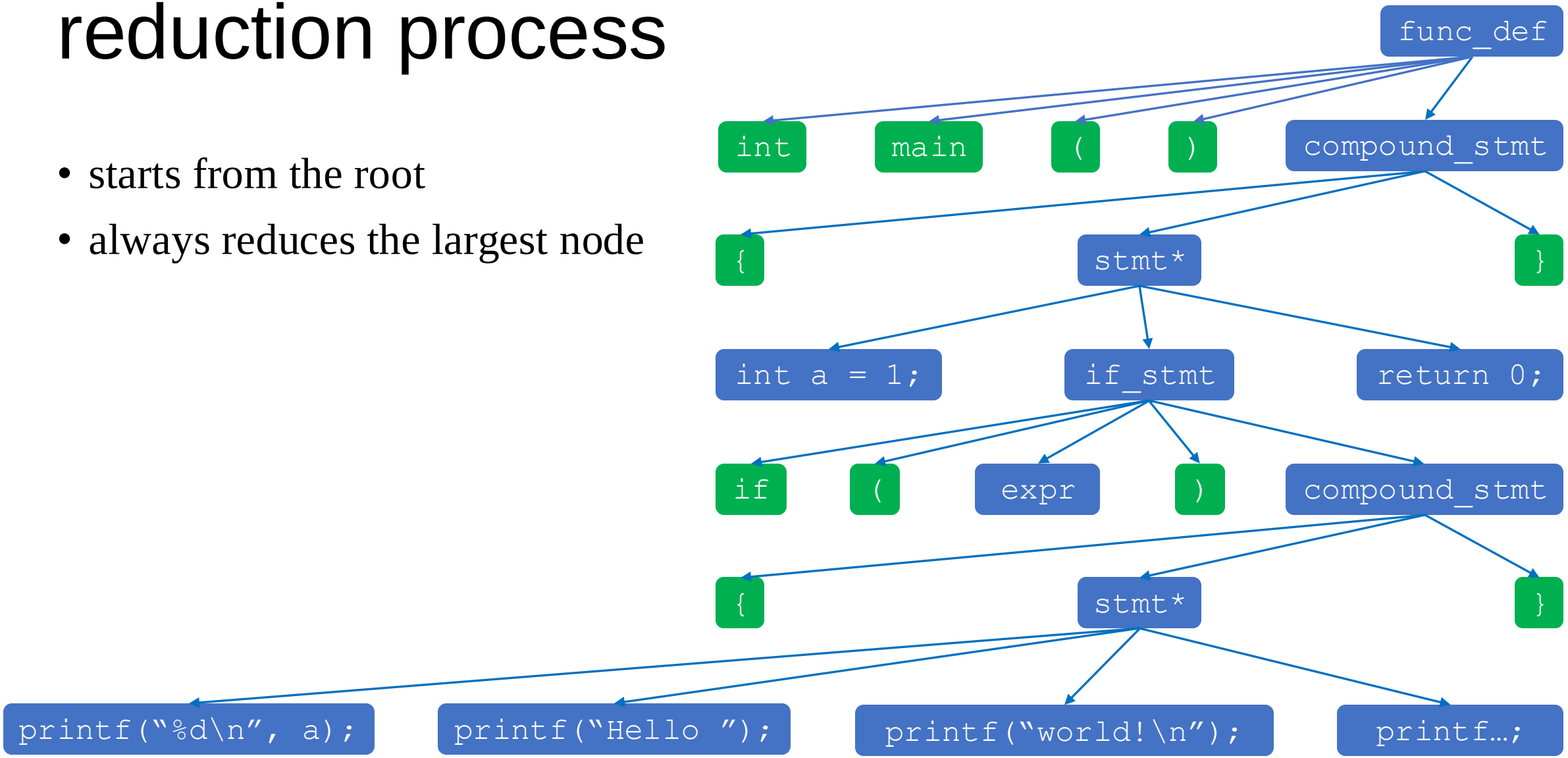
reduction process

- starts from the root
- always reduces the largest node

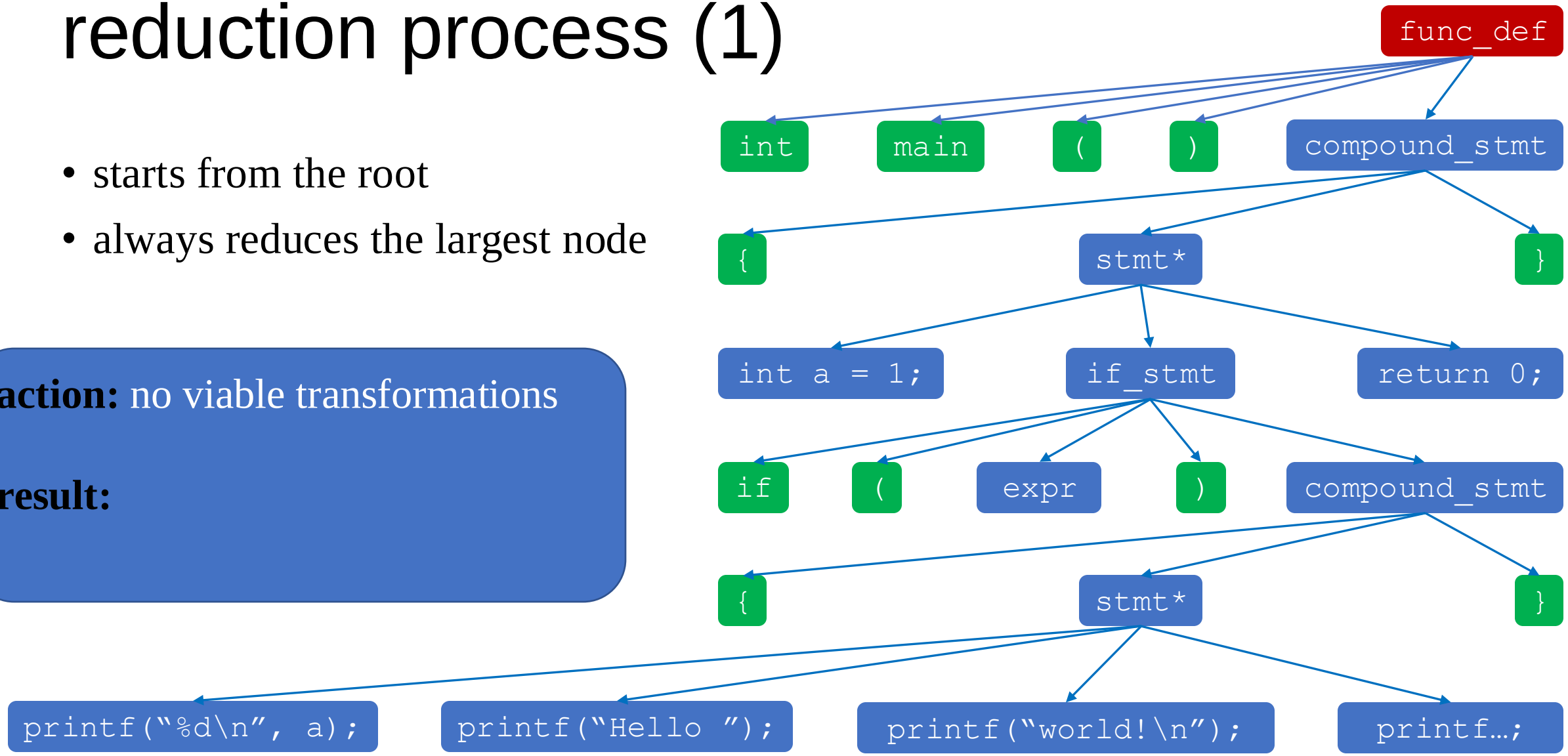


reduction process (1)

- starts from the root
- always reduces the largest node

action: no viable transformations

result:

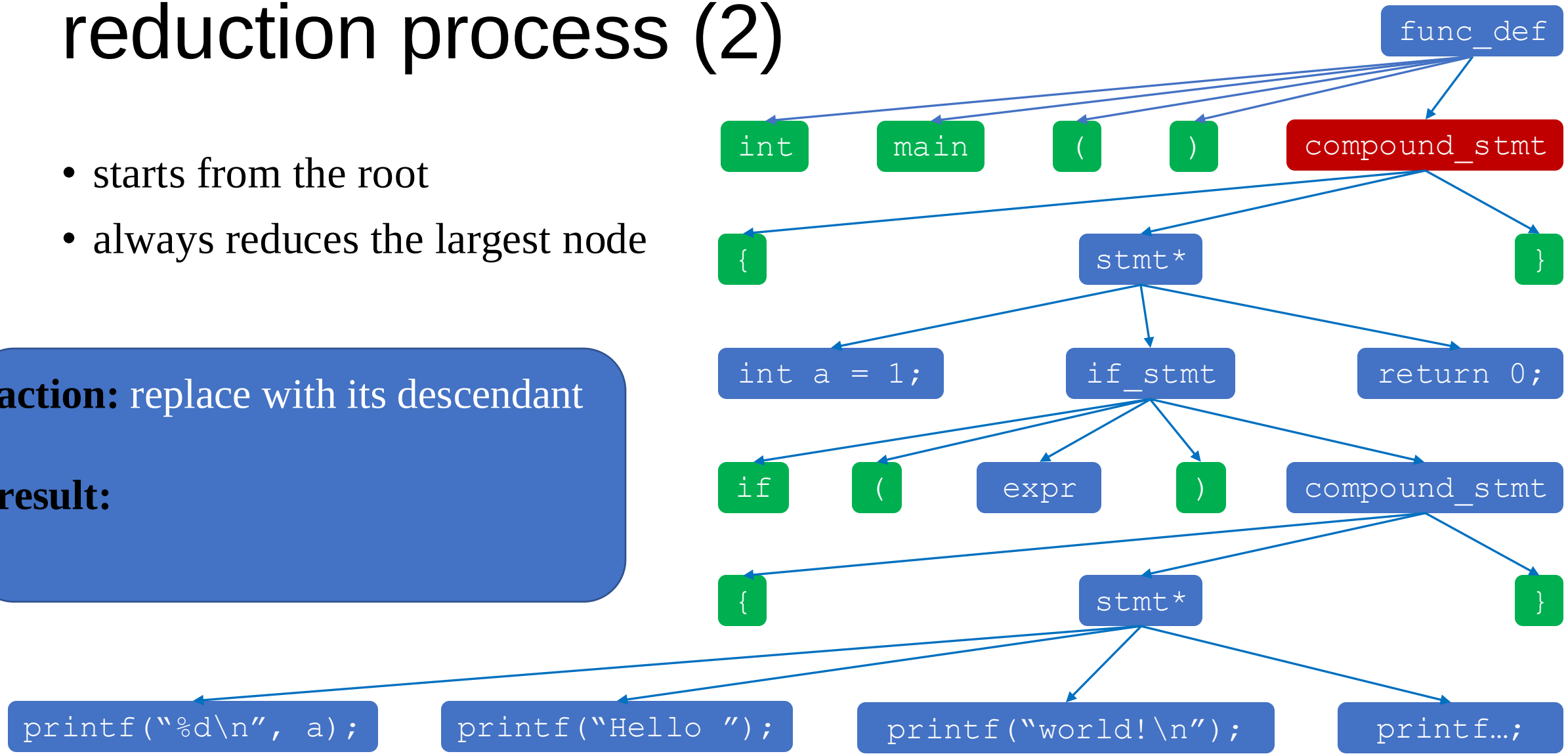


reduction process (2)

- starts from the root
- always reduces the largest node

action: replace with its descendant

result:



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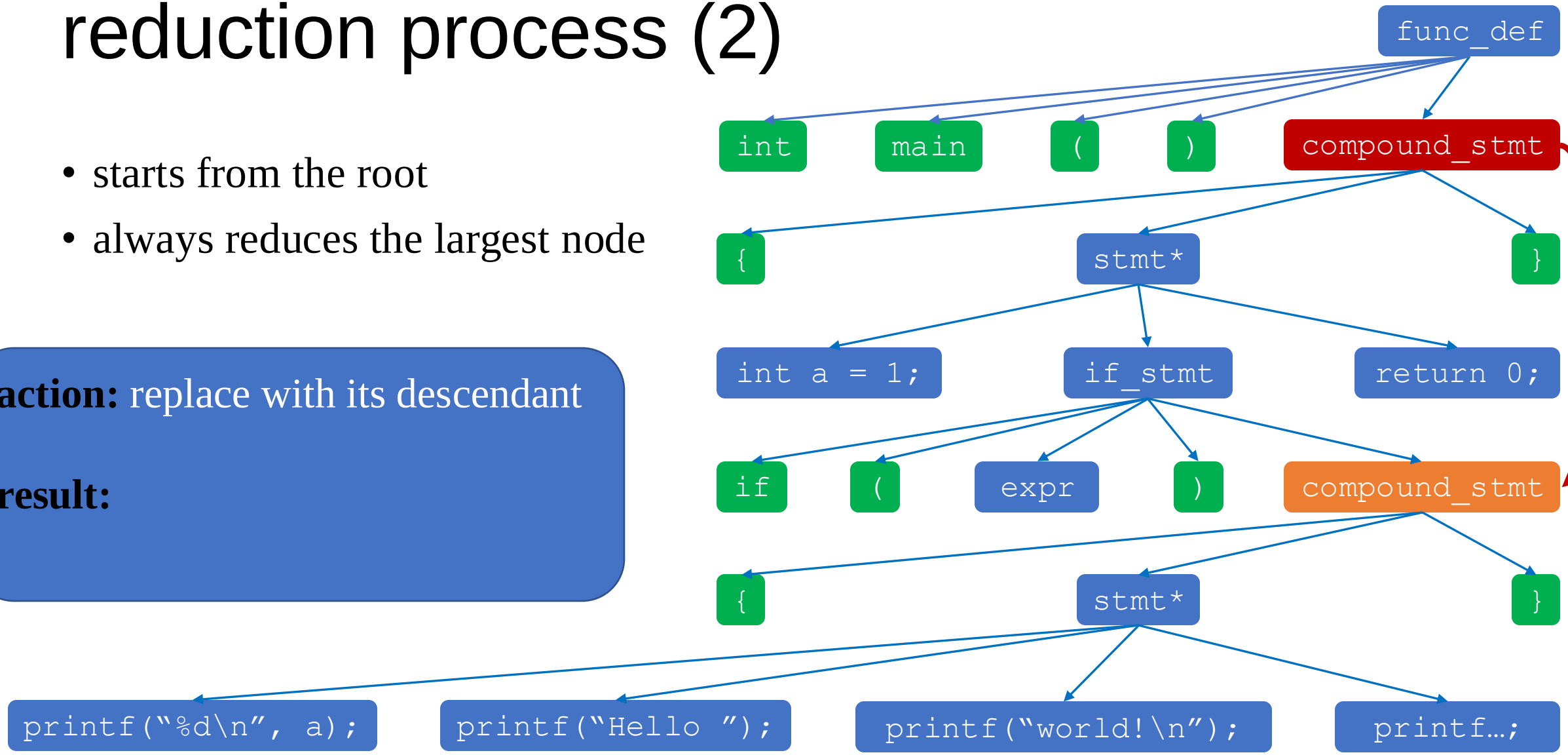

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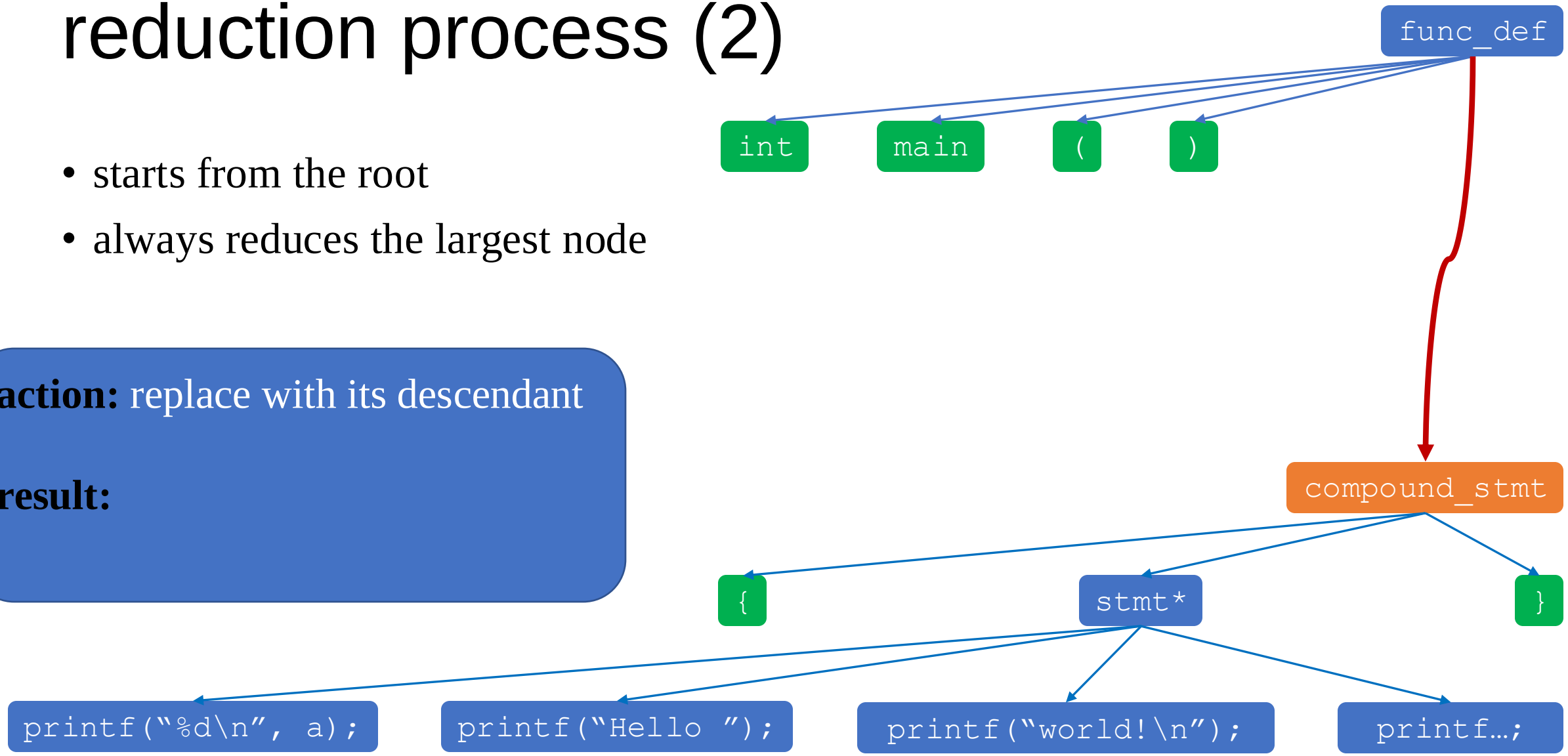

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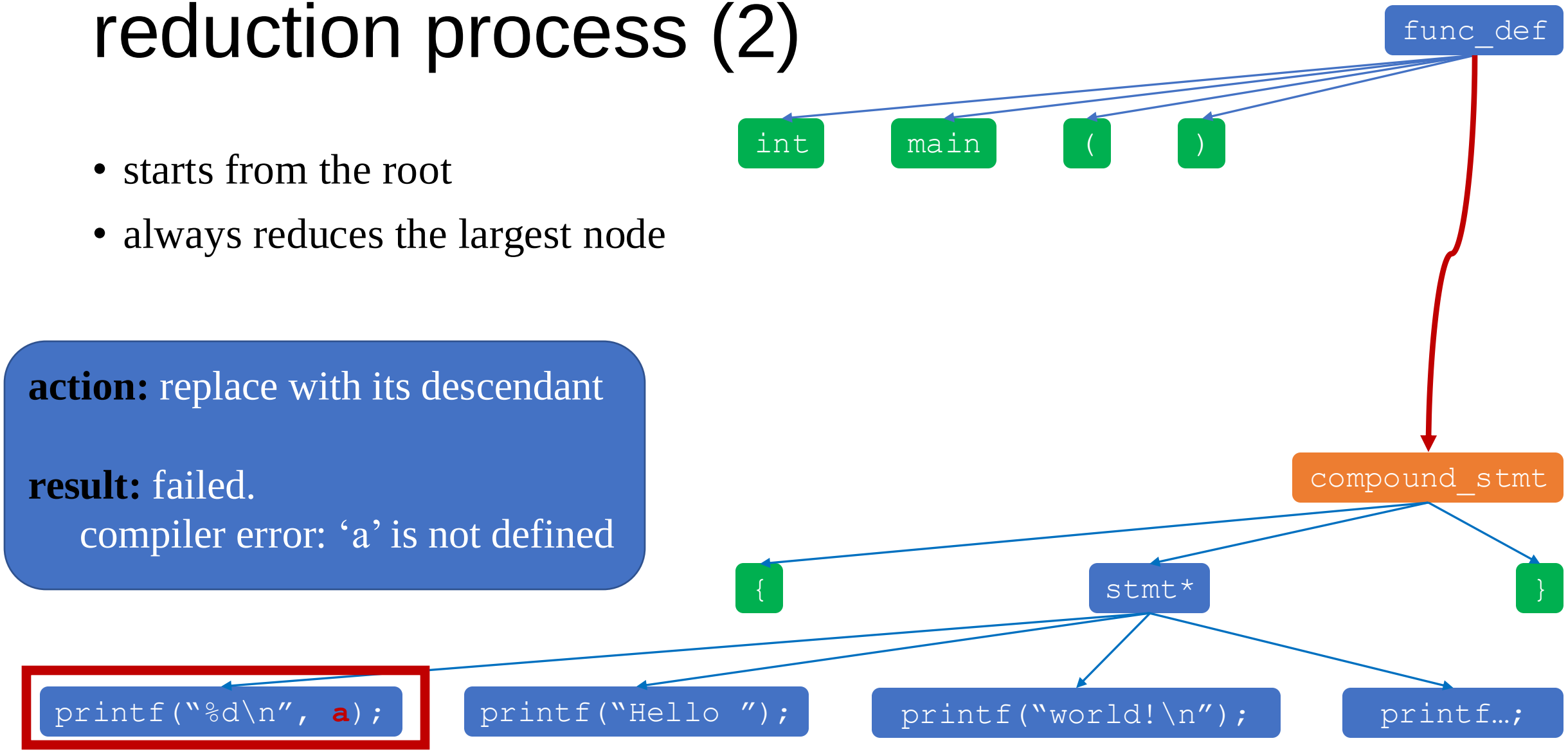

action: replace with its descendant

result: failed.
compiler error: 'a' is not defined

reduction process (3)

- starts from the root
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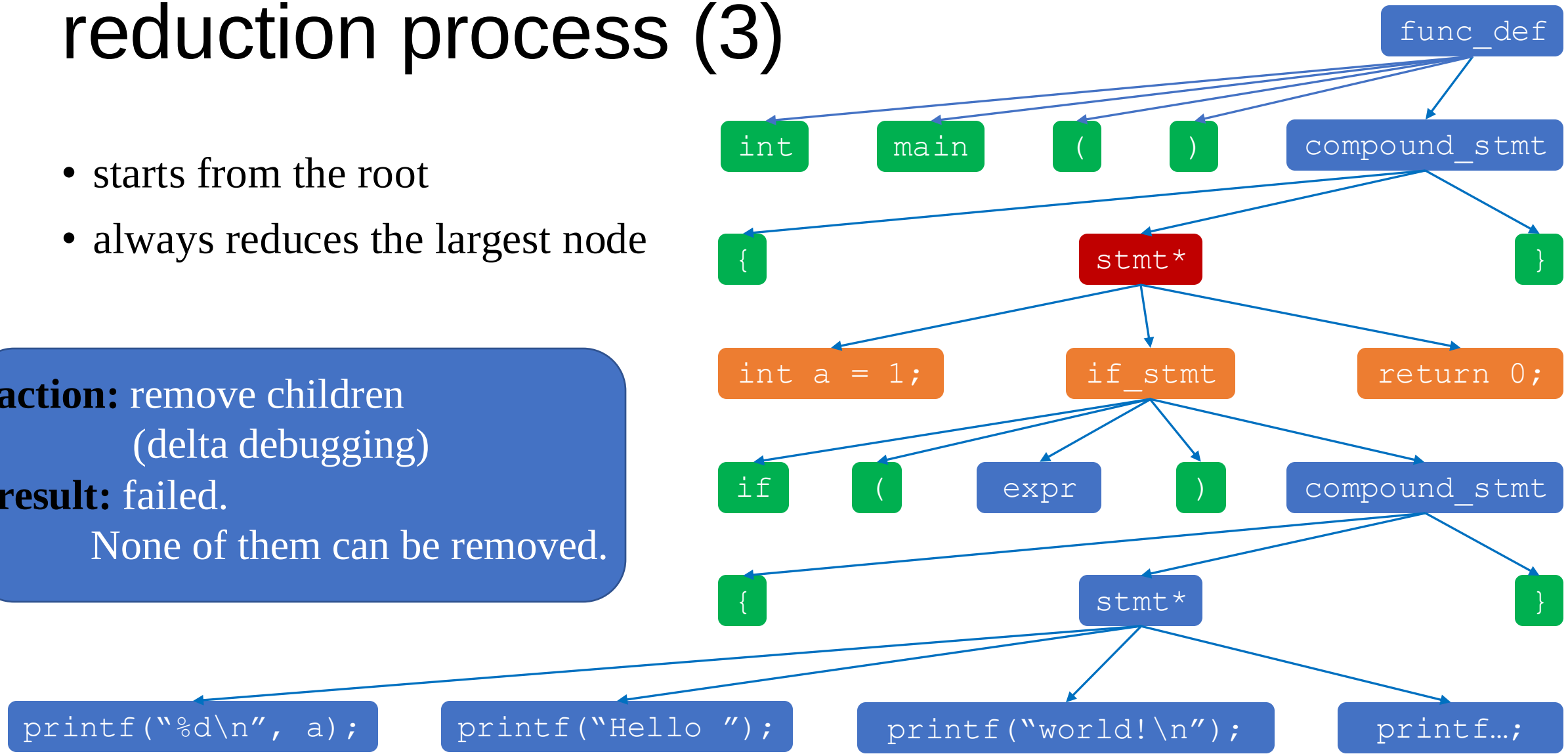
action: remove children
(delta debugging)
result: failed.
None of them can be removed.

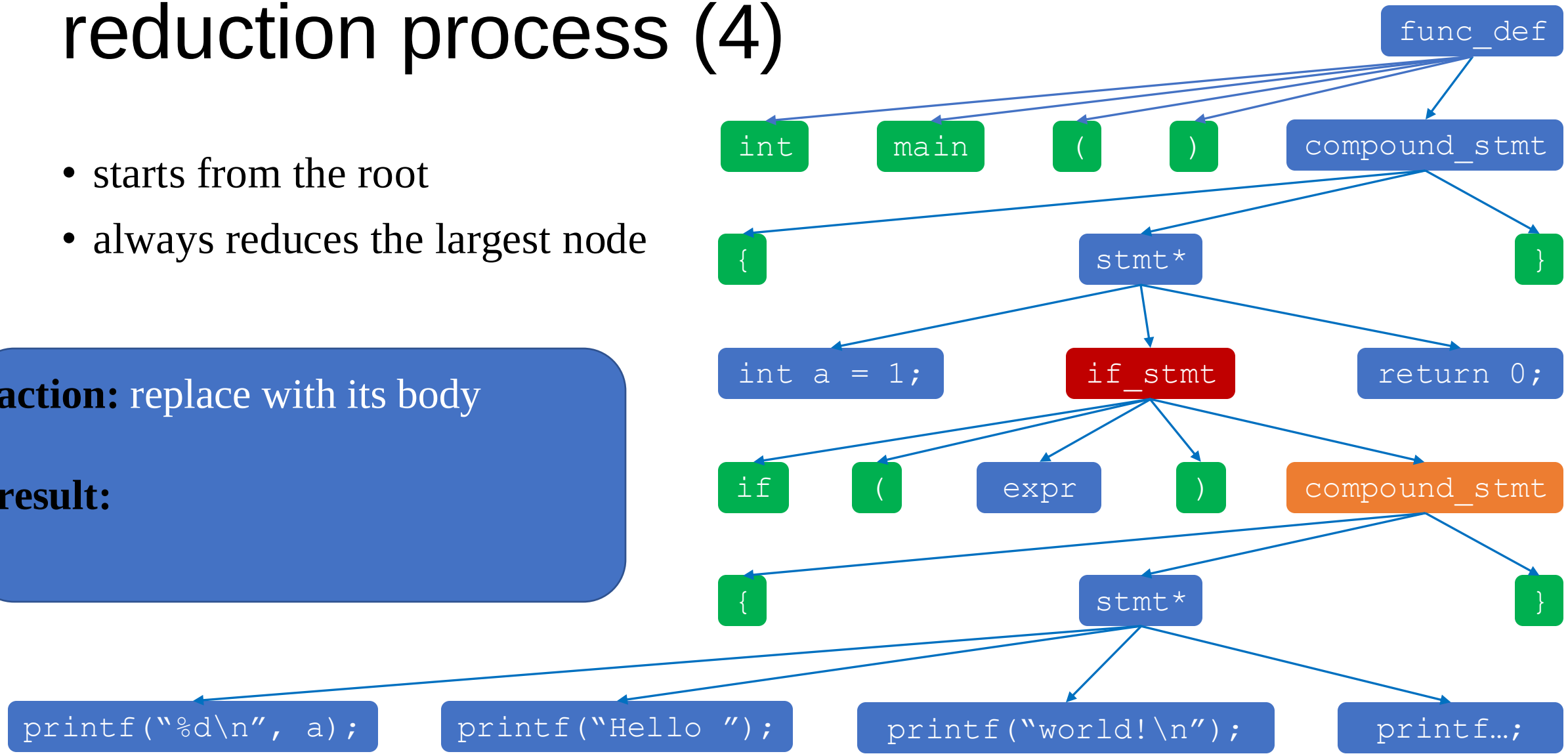


reduction process (4)

- starts from the root
- always reduces the largest node

action: replace with its body

result:



reduction process (4)

- starts from the root
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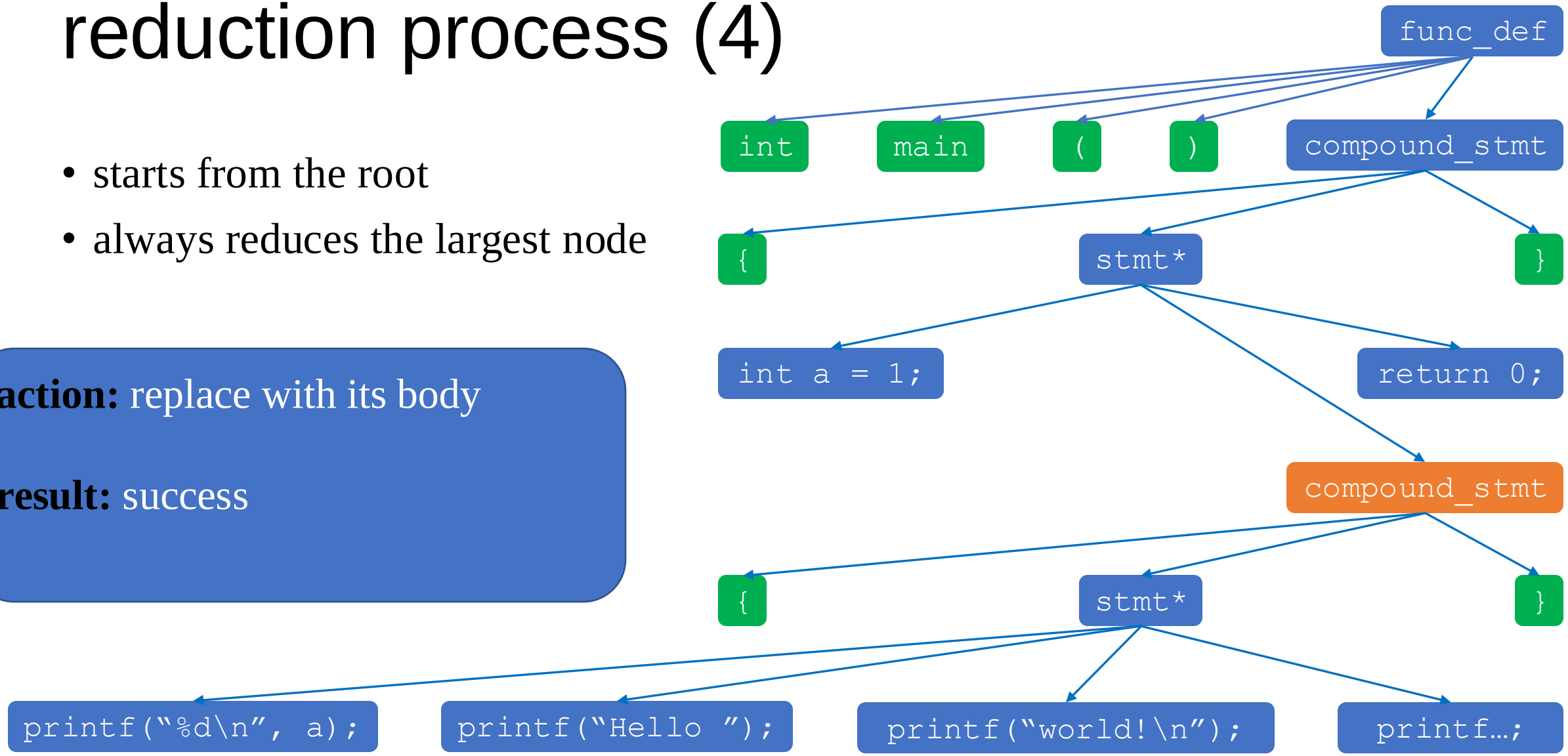
action: replace with its body

result: success



reduction process (5)

- starts from the root
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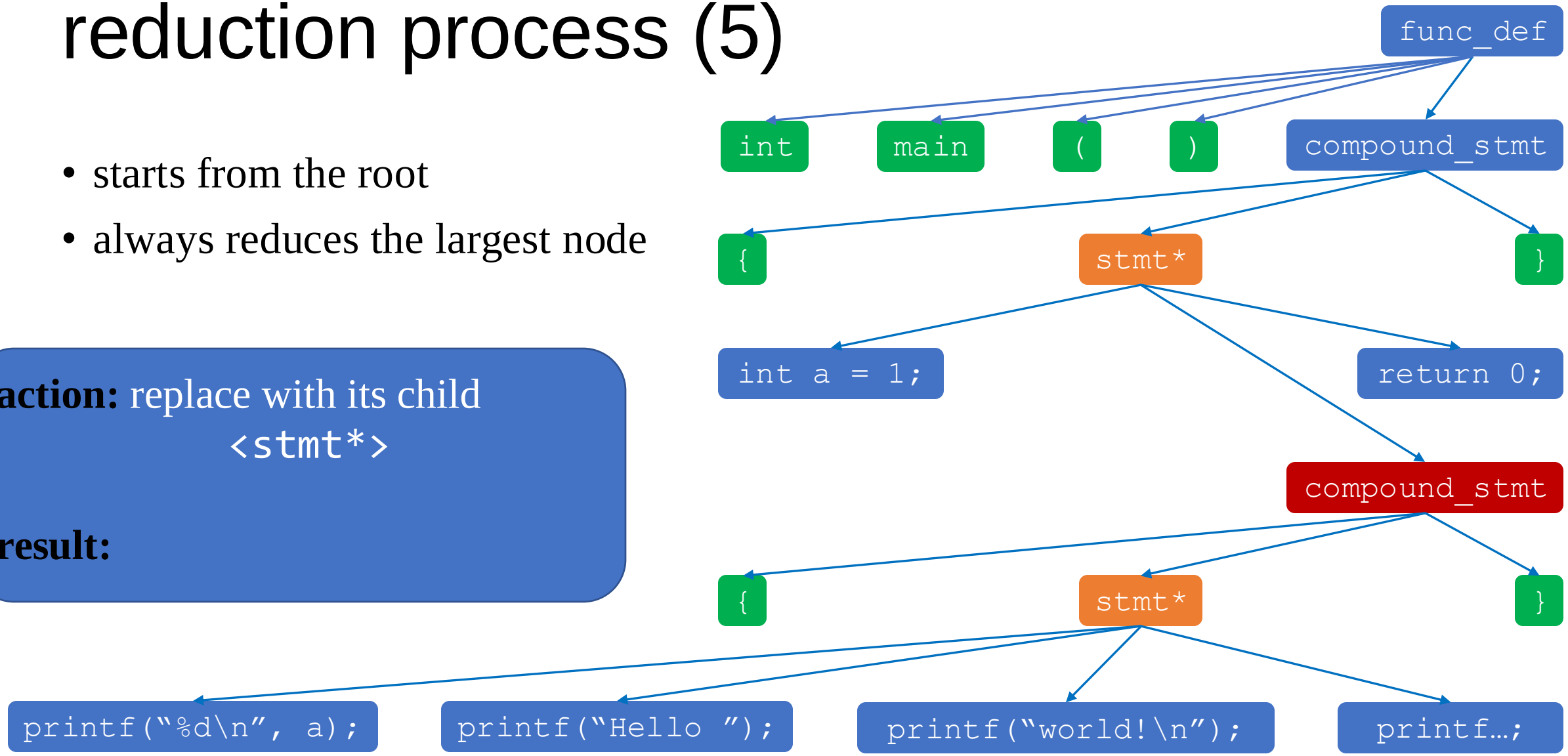
action: replace with its child
<stmt*>

result:



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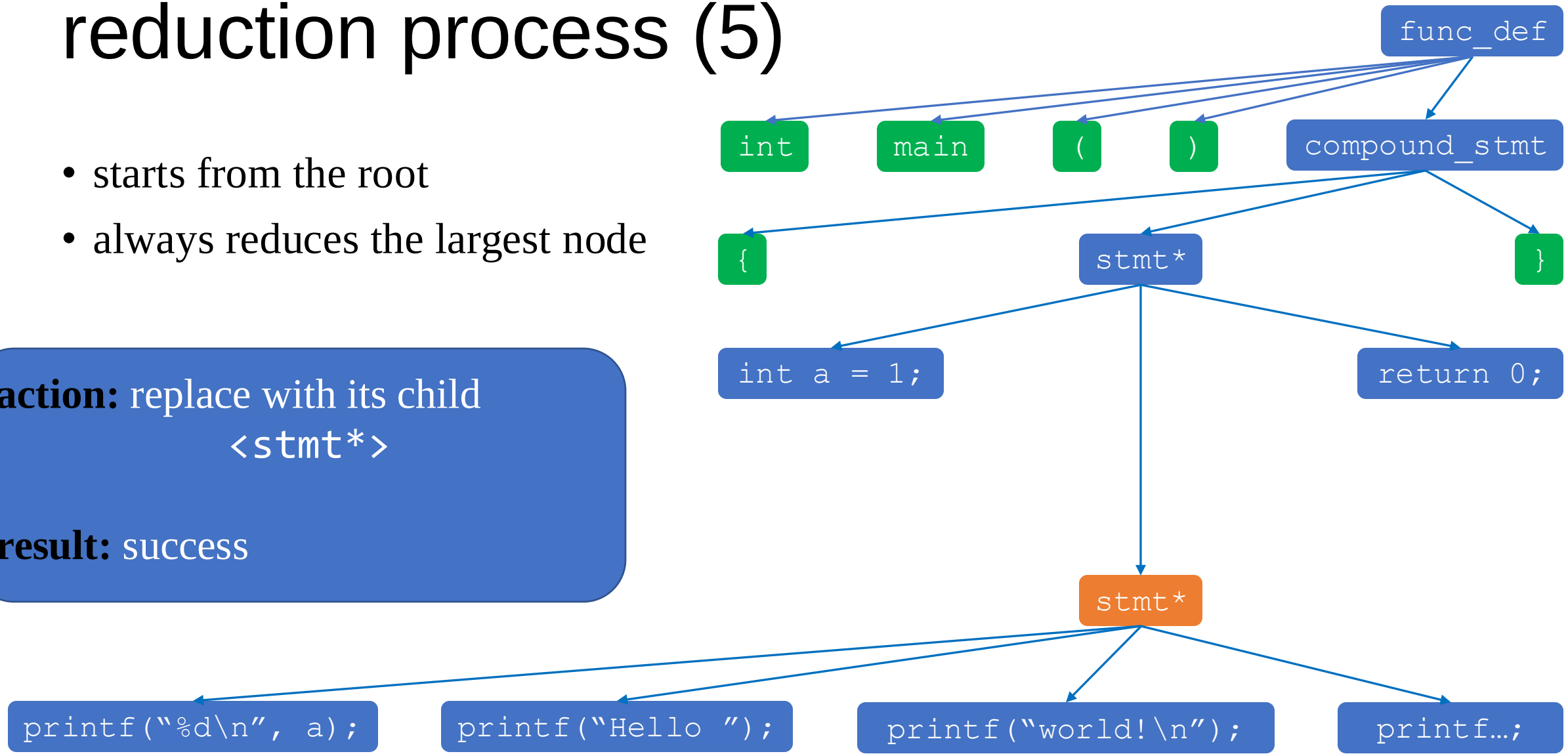
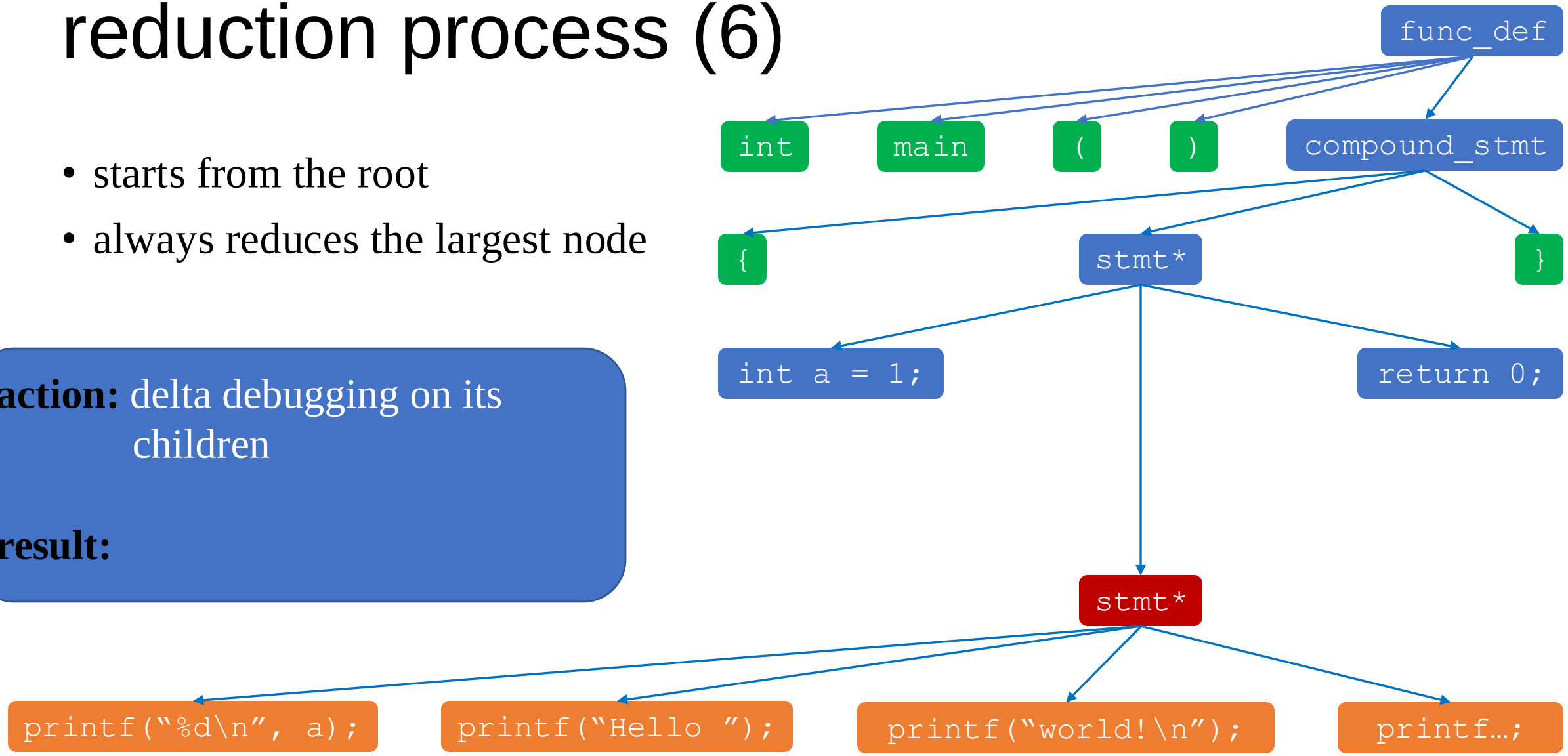


reduction process (6)

- starts from the root
- always reduces the largest node

action: delta debugging on its children

result:



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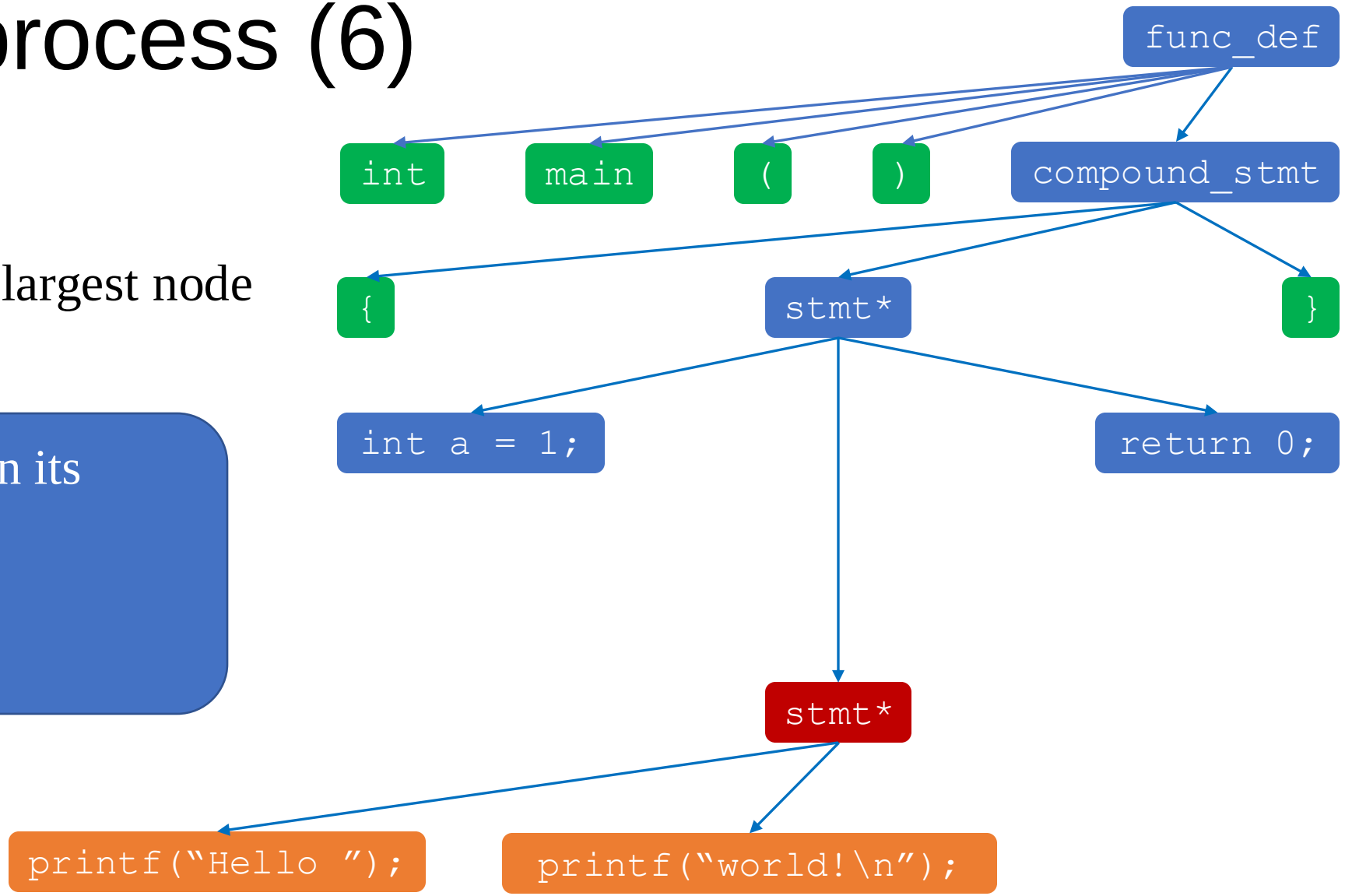

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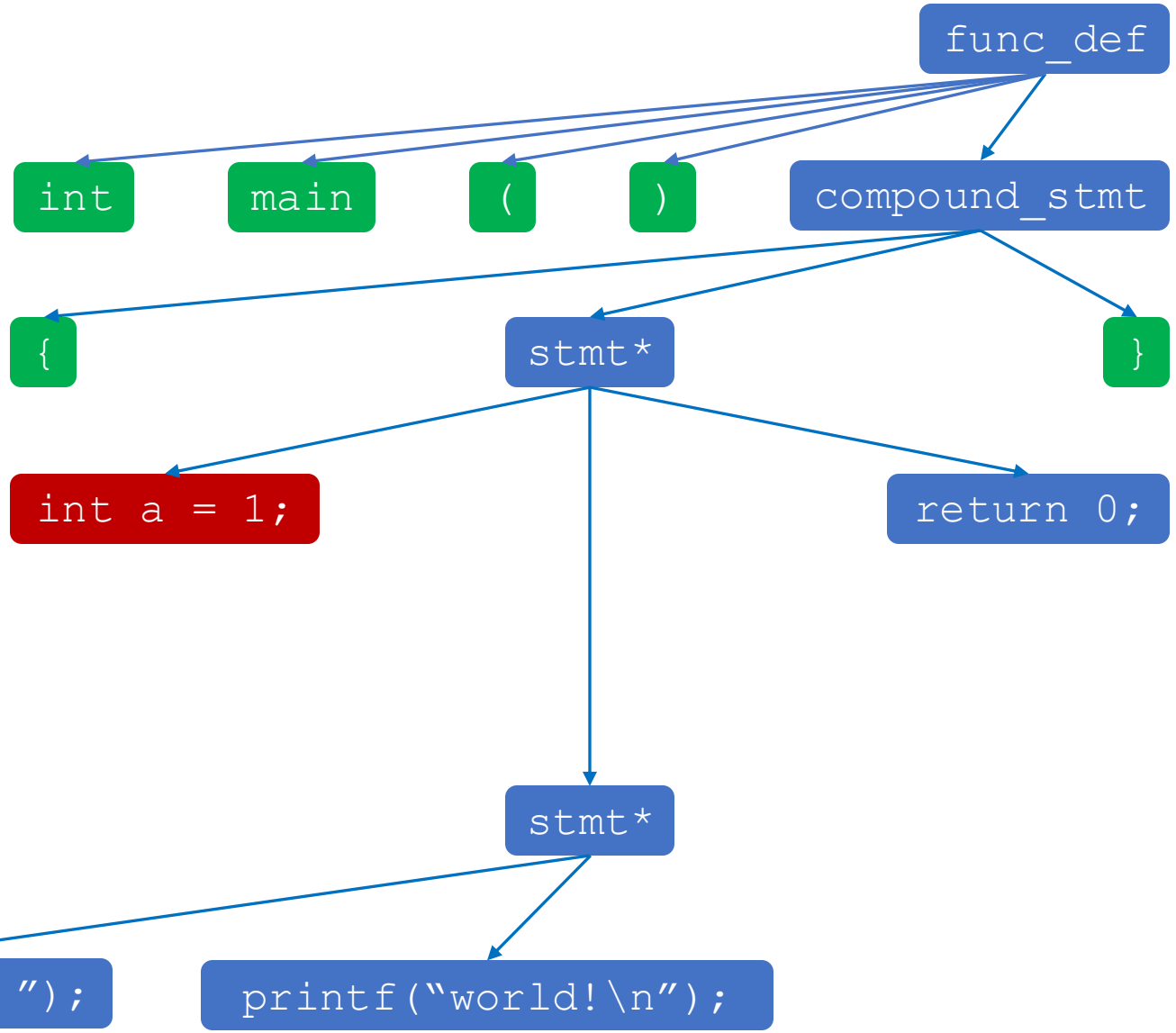


later

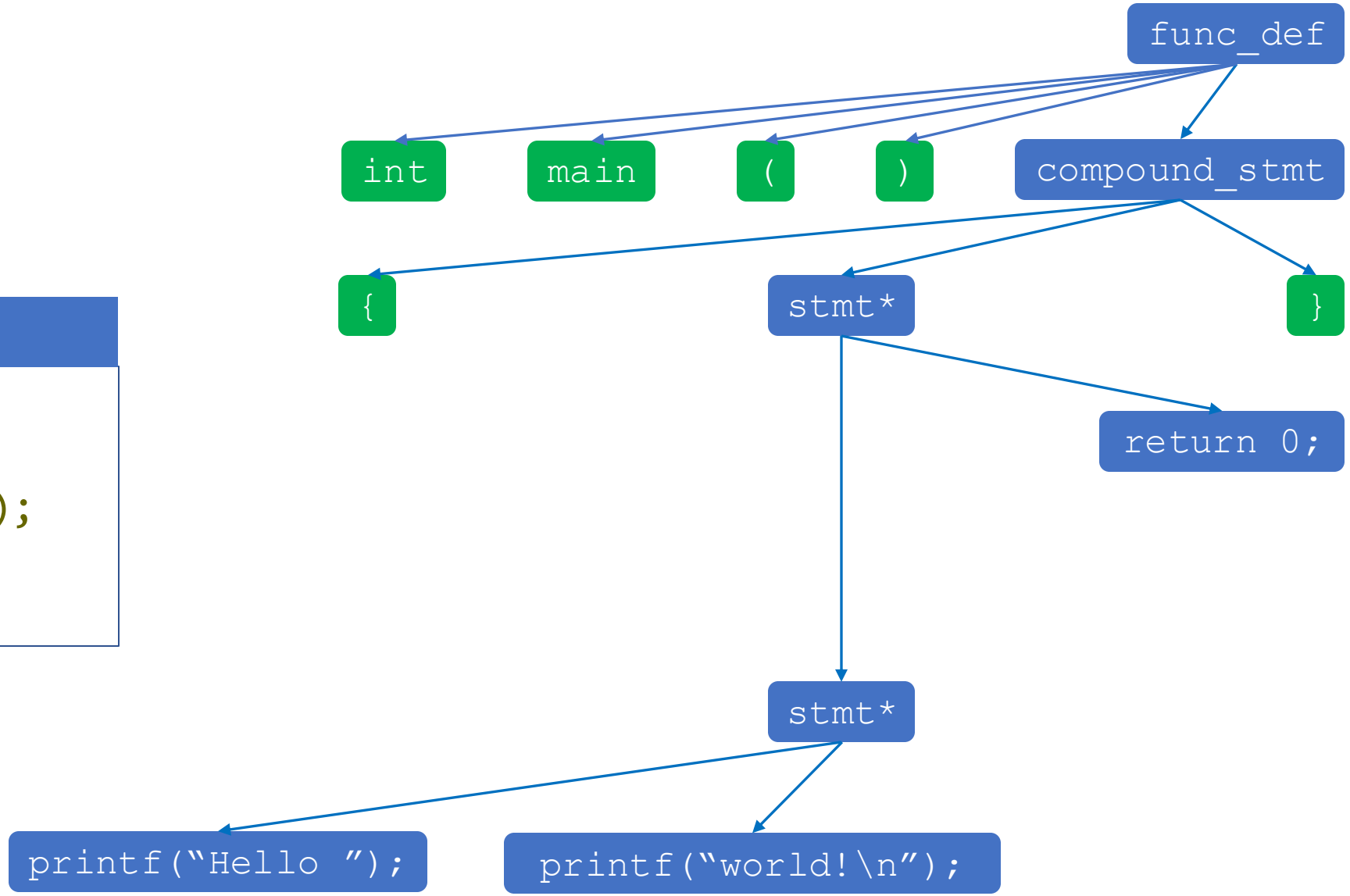
```
int a = 1;
```

will be deleted.

final result

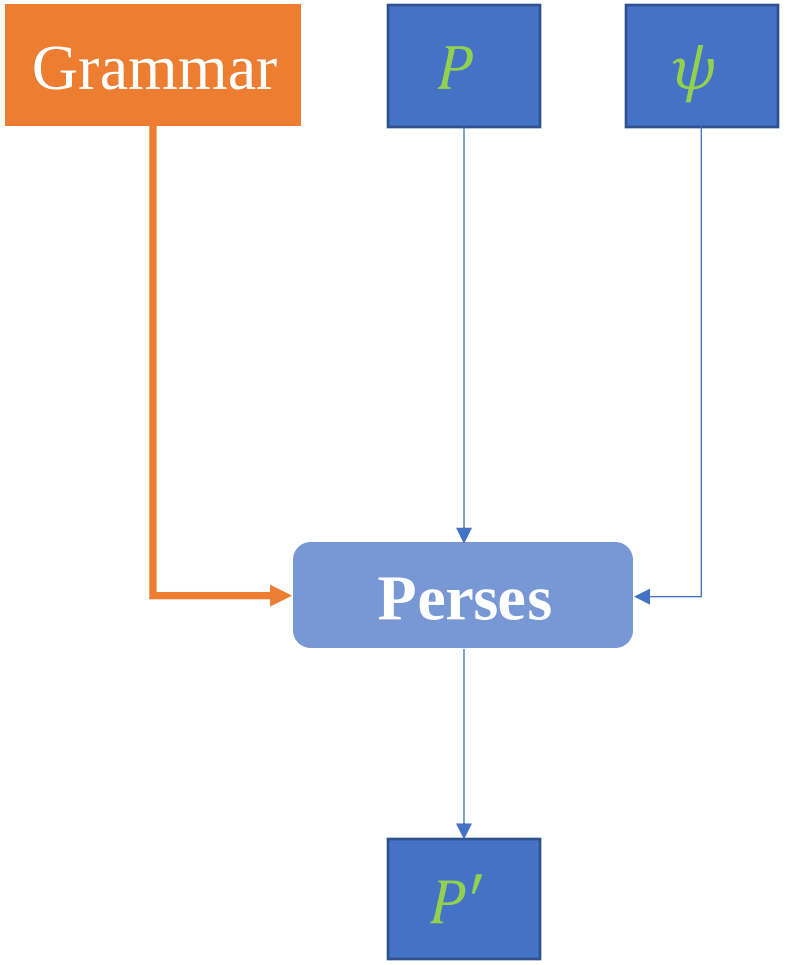
ideal result

```
int main() {
 printf("Hello ");
 printf("world!\n");
 return 0;
}
```



Perses normal form

- Perses relies on quantifiers
  - `*`, `+`, `?`
- A grammar can be written recursively
  - `<stmt_list> ::= <stmt> <stmt_list>`
    `| ϵ`



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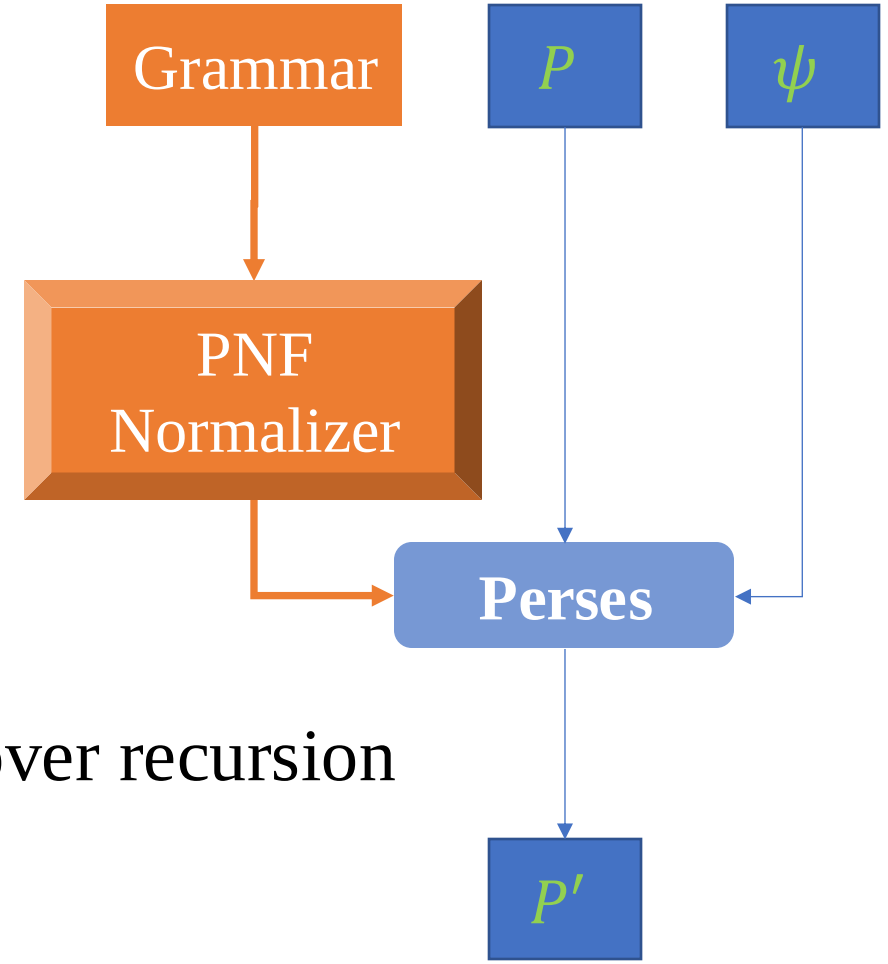

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  - `*`, `+`, `?`
- A grammar can be written recursively
  - `<stmt_list> ::= <stmt> <stmt_list>`
    `| ϵ`
- Perses Normal Form: in favor of `*`, `+`, `?` over recursion
  - `<stmt_list> ::= <stmt>*`
- Propose an automatic conversion algorithm (section 4.1 in icse'18)

evaluation

- benchmarks
  - 20 C programs: each triggered a bug in a stable compiler release
    - GCC, Clang
  - size: 6K ~ 212K tokens
- comparison
  - DD: delta debugging
  - HDD: hierarchical delta debugging
  - C-Reduce:
    - specialized reducer for C/C++
    - based on Clang front-end

evaluation

- effectiveness
  - number of tokens in the reduced result
  - number of characters in the reduced result (not meaningful for programs)
- efficiency
  - time (wall time of the reduction process)
  - number of queries/tests/variants
  - reduction speed (#tokens deleted per second)

evaluation – effectiveness

size of reduced programs (mean)					
	original	DD	HDD	C-Reduce	**Perses**
size (#)	94,486	4,573	575	90	**257**
ratio (Perses/other)		6%	45%	285%	**100%**

evaluation – efficiency (1)

A property check ψ takes constant time

→ then number of ψ checks becomes a good measure of efficiency.

→ more checks mean more reduction time

number of property checks				
	DD	HDD	C-Reduce	**Perses**
#	78,305	16,886	27,359	**5,095**
ratio (Perses/other)	7%	30%	19%	**100%**

evaluation – efficiency (2)

reduction time				
	DD	HDD	C-Reduce	**Perses**
seconds	9,710	4,658	3,675	**2,198**
ratio (Perses/other)	23%	47%	60%	**100%**

reduction speed				
	DD	HDD	C-Reduce	**Perses**
tokens/seconds	20	37	33	**63**
ratio (Perses/other)	3.2x	1.7x	1.9x	**100%**

conclusion

- general, syntax-guided program reduction
- outperform DD, HDD, complement C-Reduce on C/C++
  - smaller reduction results in less time
- language-agnostic and fully automated support for any? new language