Lazy evaluation in Haskell

exploring some mental models and implementations

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Rev. 0.00.0
WIP

Lazy,... zzz

..., It's fun.

NOTE

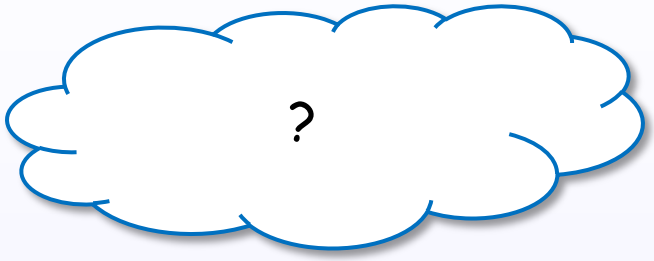
- Meaning of terms are different by communities.
- There are a lot of good documents. Please see also references.
- This is written for GHC's Haskell.

Contents

Introduction

What is an expression?

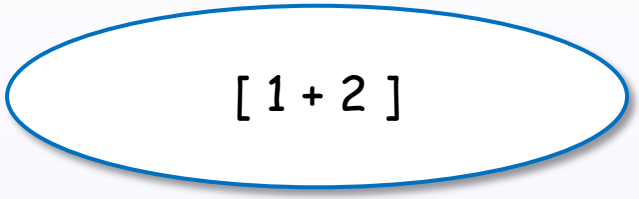
An expression



References : [1]

An expression denotes a value

An expression

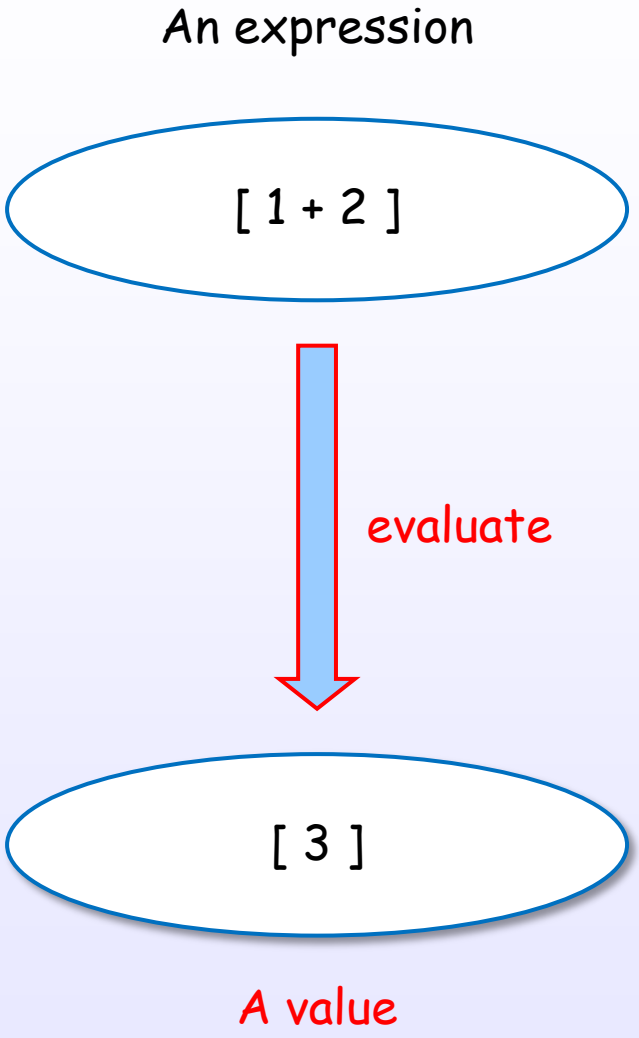


[HR2010]

[Bird, Chapter 2]

References : [1]

An expression evaluates to a value

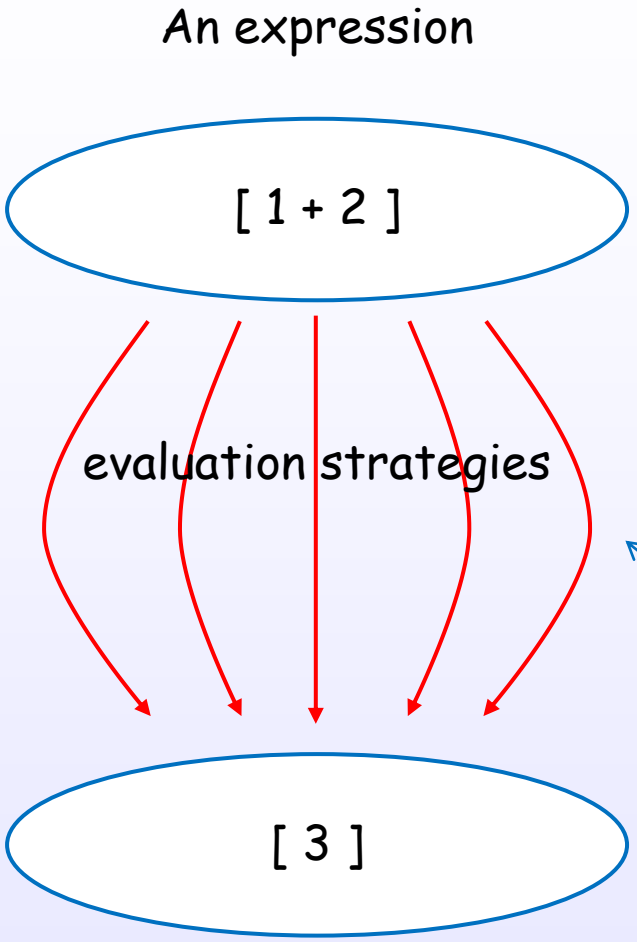


[HR2010]

[Bird, Chapter 2]

References : [1]

There are many evaluation approaches



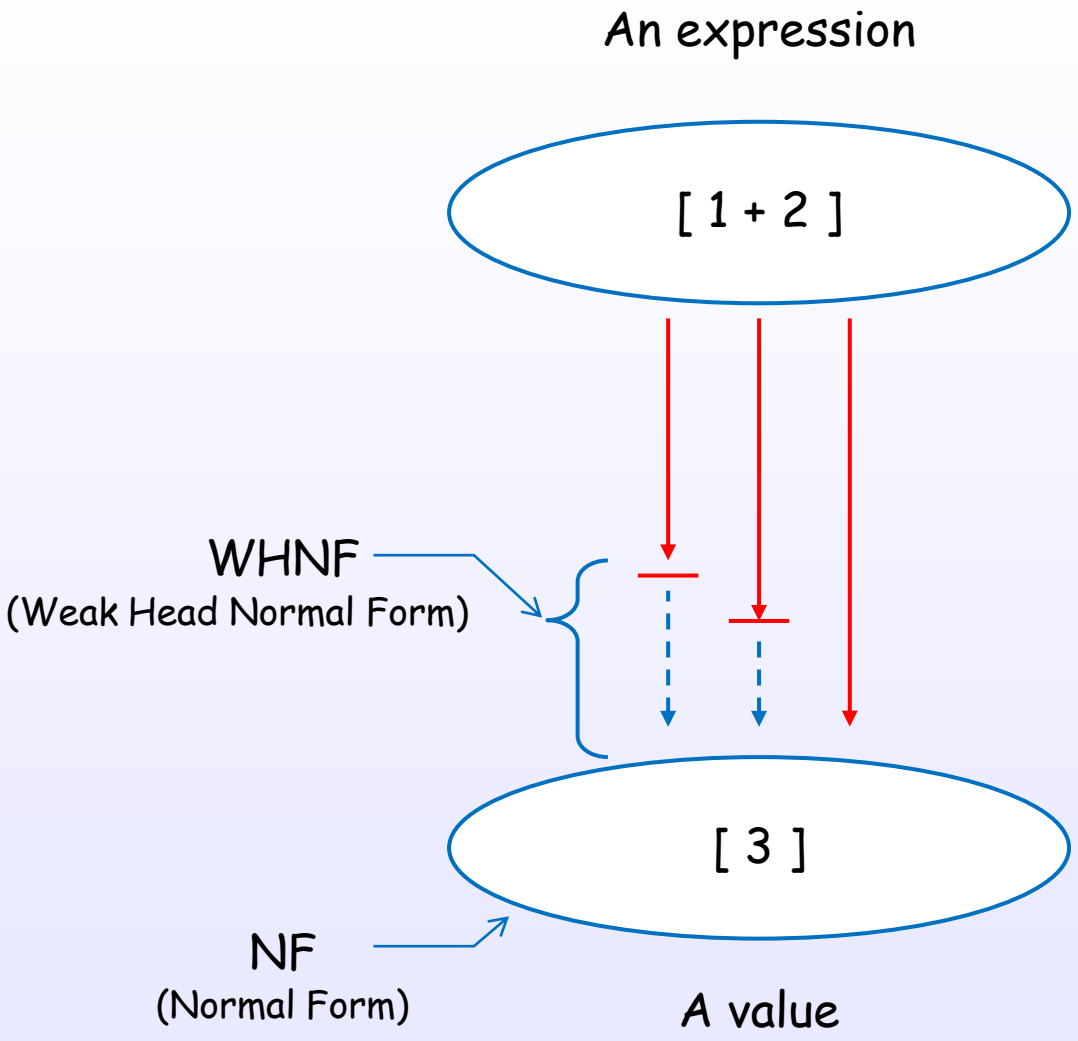
- Strict, Non-strict evaluation
- Eager, Lazy evaluation
- Call-by-value, Call-by-name, Call-by-need, …
- Innermost, Outermost
- Normal order, Application order
- …

[Bird, Chapter 2, 7]

[TAPL, Chapter 3]

References : [1]

There are some evaluation levels



[Terei]

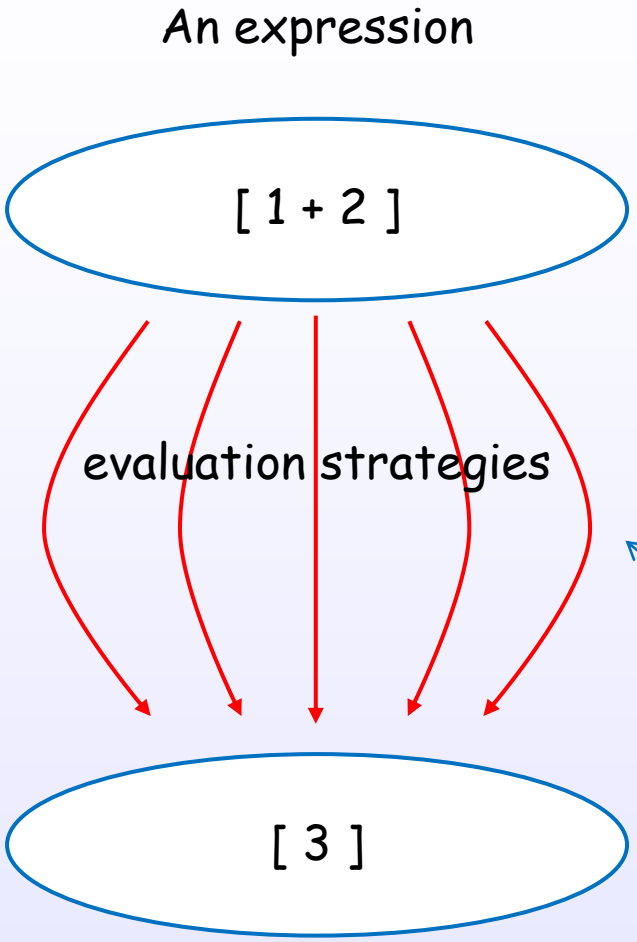
[Bird, Chapter 2, 7]

[TAPL, Chapter 3]

References : [1]

Evaluations

There are many evaluation approaches



- Strict, Non-strict evaluation
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- Call-by-value, Call-by-name, Call-by-need, …
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- …

[Bird, Chapter 2, 7]

[TAPL, Chapter 3]

References : [1]

Evaluation layers

denotational semantics

evaluation strategy

evaluation implementation

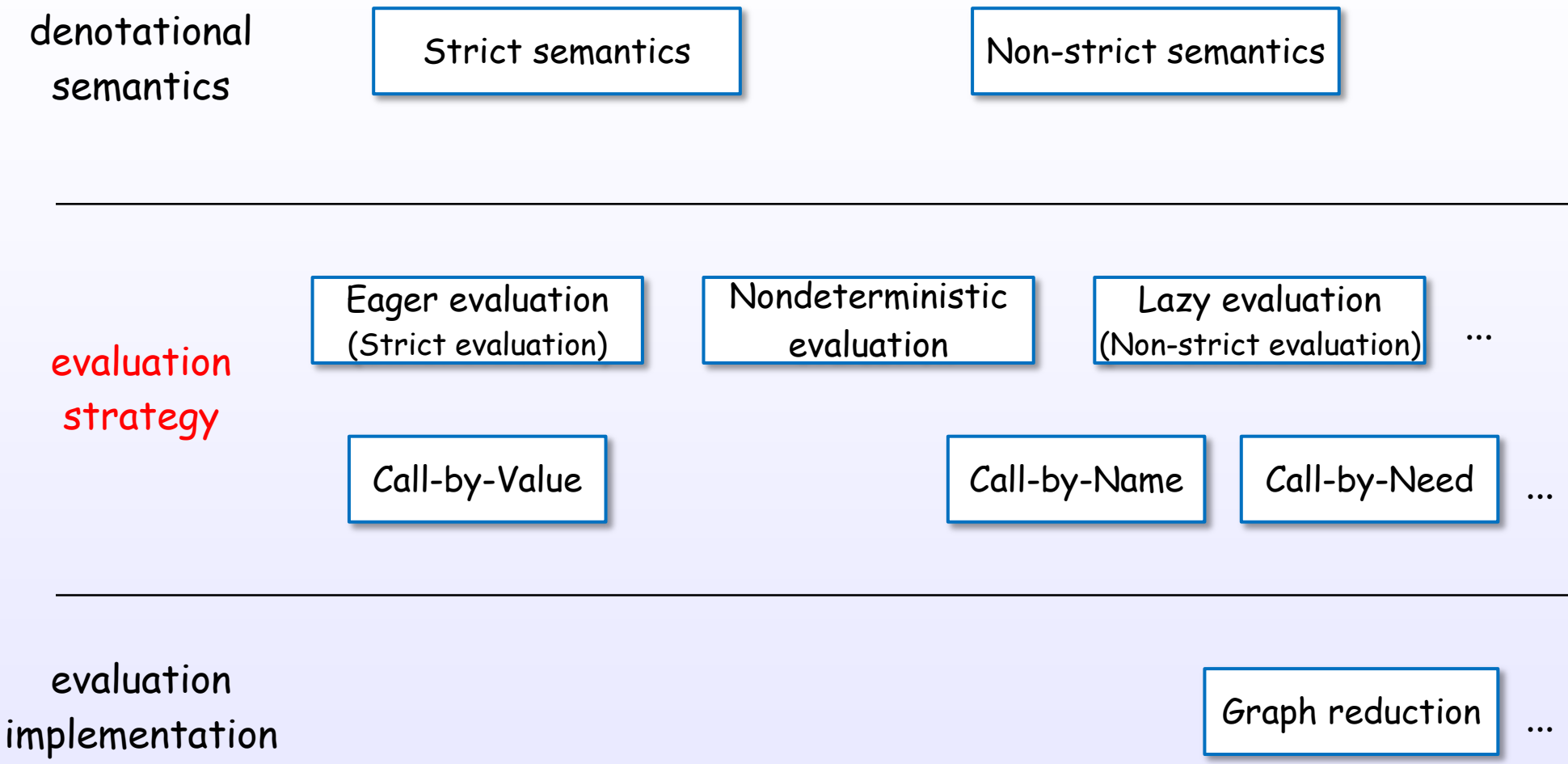
[Bird, Chapter 7]

[Hutton, Chapter 8]

[TAPL, Chapter 3]

References : [1]

Evaluation layers



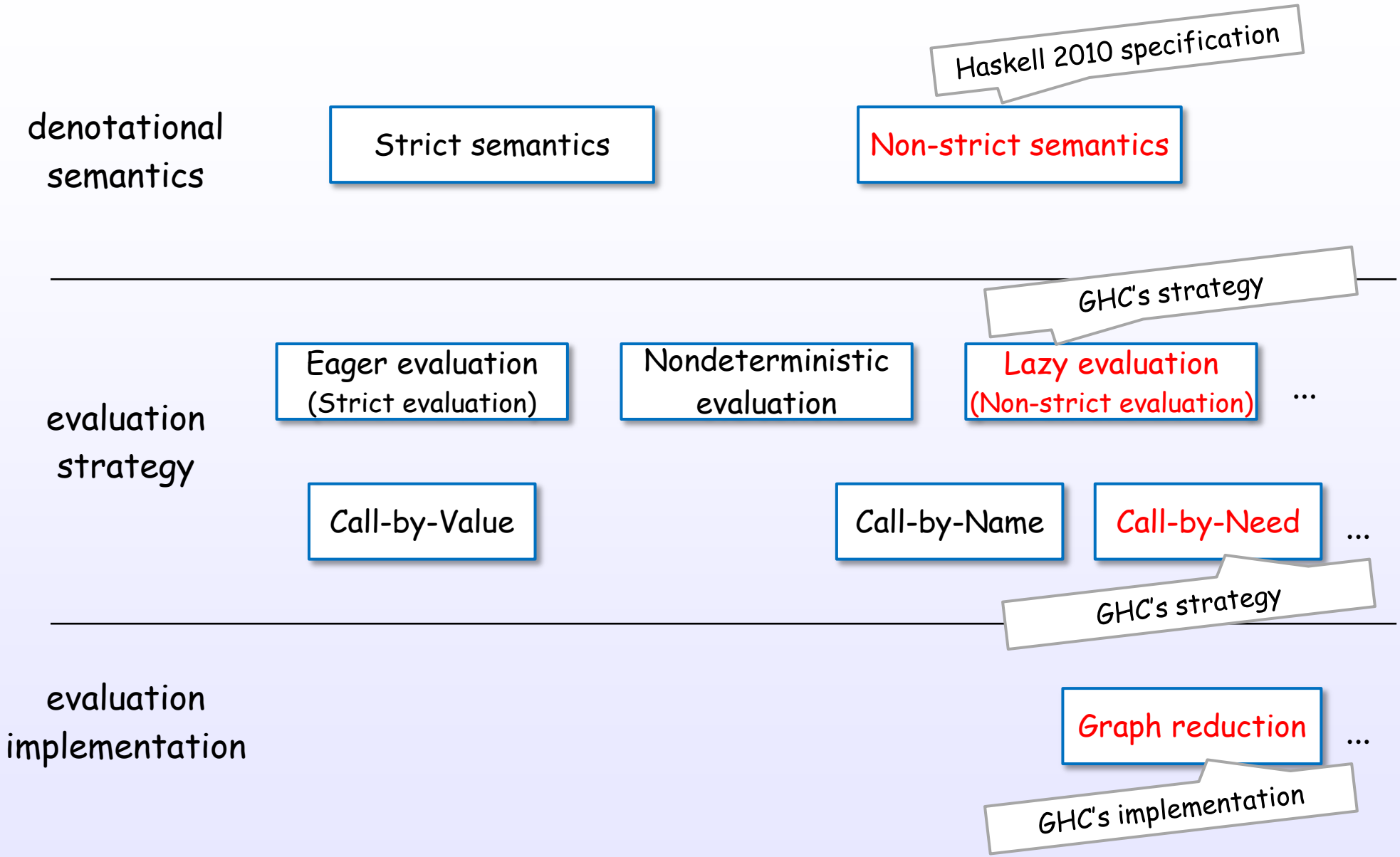
[Bird, Chapter 7]

[Hutton, Chapter 8]

[TAPL, Chapter 3]

References : [1]

Evaluation layers for GHC's Haskell



References : [1]

Simple example of both evaluations

default

C, Java, JavaScript, Python, OCaml, Scheme, ...

Eager evaluation
(Strict evaluation)

square (1 + 2)

argument evaluation first

square (3)

3 * 3

9

default

Haskell (GHC), ...

Lazy evaluation
(Non-strict evaluation)

square (1 + 2)

apply first

(1 + 2) * (1 + 2)

(3) * (3)

9

[Bird]
[Hutton]

References : [1]

Simple example of both evaluations

Eager evaluation
(Strict evaluation)

square (1 + 2)

square (3)

argument evaluated

3 * 3

9

Lazy evaluation
(Non-strict evaluation)

square (1 + 2)

(1 + 2) * (1 + 2)

argument evaluation delayed !

(3) * (3)

9

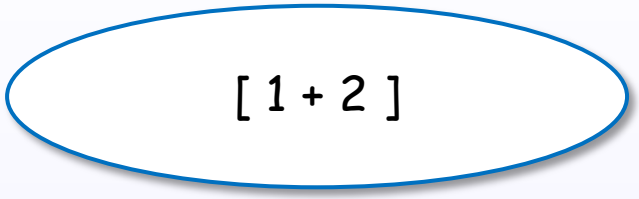
[Bird]
[Hutton]

References : [1]

Expressions in Haskell

An expression denotes a value

An expression

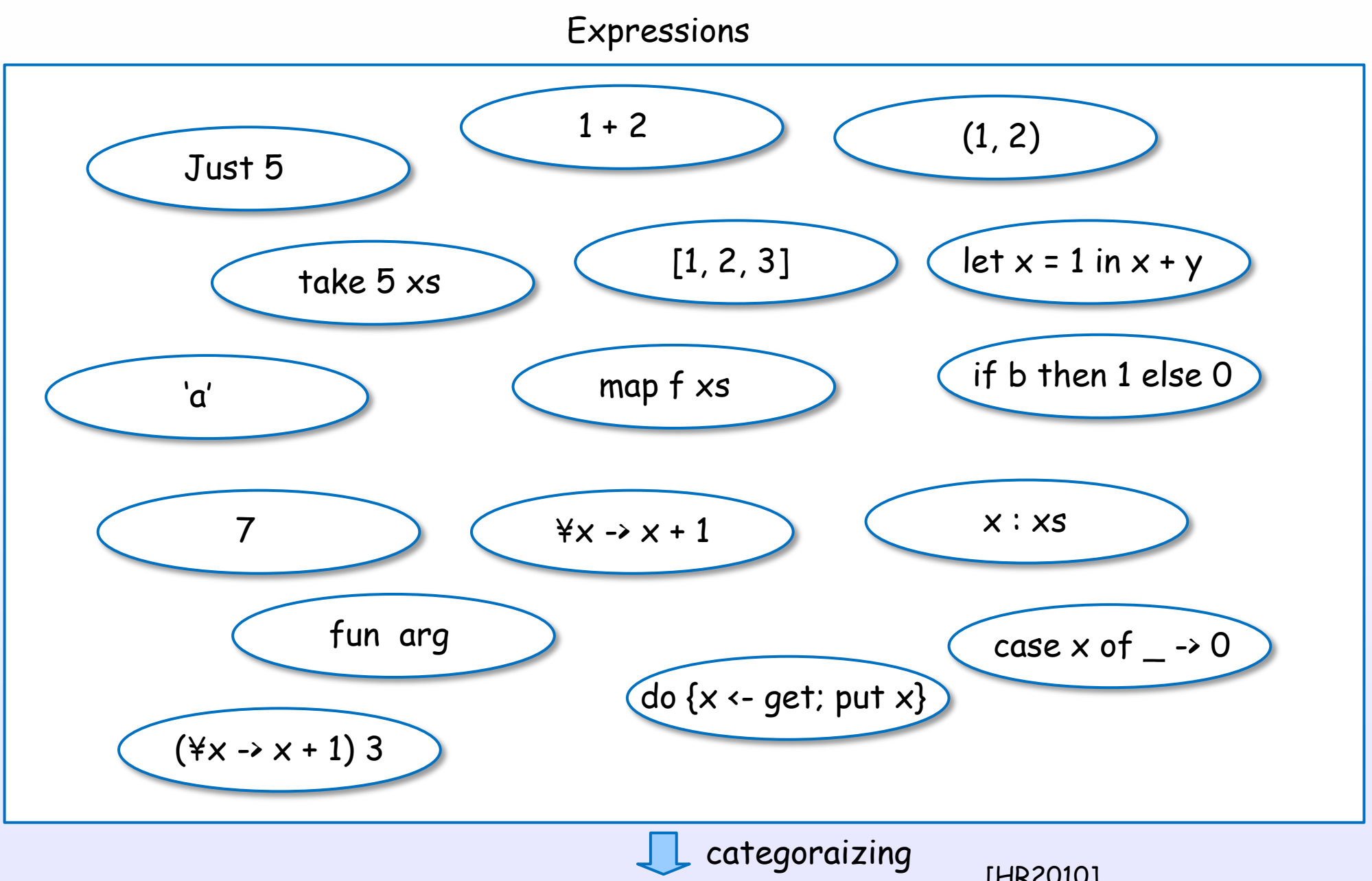


[HR2010]

[Bird, Chapter 2]

References : [1]

There are many expressions in Haskell



[HR2010]

[Bird, Chapter 2]

References : [1]

Expression categories in Haskell

lambda abstraction

```
¥x -> x + 1
```

let expression

```
let x = 1 in x + y
```

conditional

```
if b then 1 else 0
```

case expression

```
case x of _ -> 0
```

do expression

```
do {x <- get; put x}
```

general constructor, literal and some forms

```
7
[1, 2, 3]
(1, 2)
'a'
x : xs
Just 5
```

function application

```
take 5 xs
(¥x -> x + 1) 3
1 + 2
map f xs
fun  arg
```

[HR2010]
[Bird, Chapter 2]

References : [1]

Specification is defined in Haskell 2010 Language Report

Haskell 2010 Language Report, Chapter 3 Expressions [1]

exp	→	*infixexp* `::` [*context* `=>`] *type*	(expression type signature)
	|	*infixexp*	
infixexp	→	*lexp qop infixexp*	(infix operator application)
	|	`-` *infixexp*	(prefix negation)
	|	*lexp*	
lexp	→	`\` $apat_1$ ... $apat_n$ `->` *exp*	(lambda abstraction, $n \geq 1$)
	|	`let` *decls* `in` *exp*	(let expression)
	|	`if` *exp* [`;`] `then` *exp* [`;`] `else` *exp*	(conditional)
	|	`case` *exp* `of` `{` *alts* `}`	(case expression)
	|	`do` `{` *stmts* `}`	(do expression)
	|	*fexp*	
fexp	→	[*fexp*] *aexp*	(function application)
aexp	→	*qvar*	(variable)
	|	*gcon*	(general constructor)
	|	*literal*	
	|	`(` *exp* `)`	(parenthesized expression)
	|	`(` exp_1 `,` ... `,` exp_k `)`	(tuple, $k \geq 2$)
	|	`[` exp_1 `,` ... `,` exp_k `]`	(list, $k \geq 1$)
	|	`[` exp_1 [`,` exp_2] `..` [exp_3] `]`	(arithmetic sequence)
	|	`[` *exp* `|` $qual_1$ `,` ... `,` $qual_n$ `]`	(list comprehension, $n \geq 1$)
	|	`(` *infixexp qop* `)`	(left section)
	|	`(` $qop_{\langle - \rangle}$ *infixexp* `)`	(right section)
	|	*qcon* `{` $fbind_1$ `,` ... `,` $fbind_n$ `}`	(labeled construction, $n \geq 0$)
	|	$aexp_{\langle qcon \rangle}$ `{` $fbind_1$ `,` ... `,` $fbind_n$ `}`	(labeled update, $n \geq 1$)

References : [1]

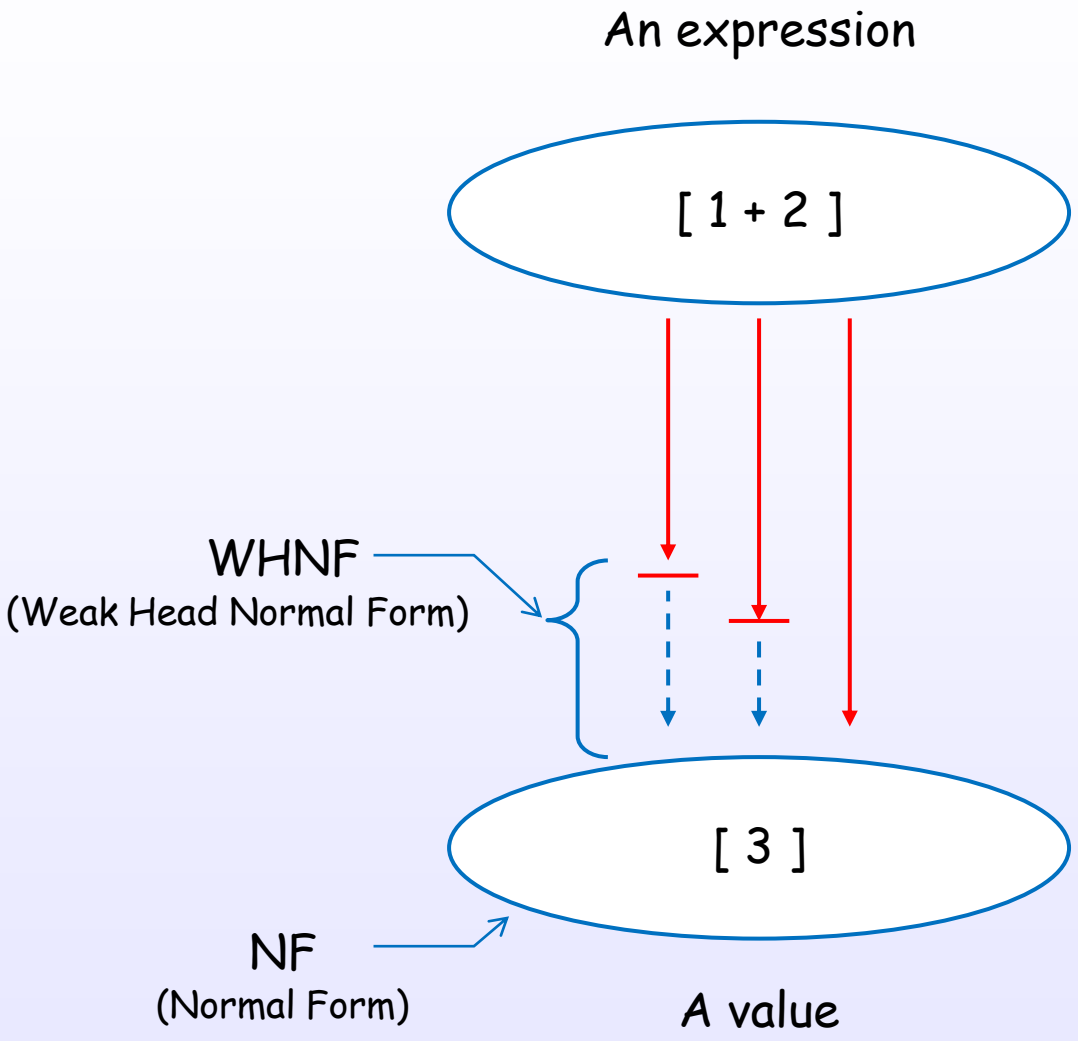
Constructor

Constructor

References : [1]

WHNF, Thunk

There are some evaluation levels



[Terei]

[Bird, Chapter 2, 7]

[TAPL, Chapter 3]

References : [1]

WHNF

[4]

normal form:
an expression without an redexes

head normal form:
an expression where the top level (head) is neither a redex NOR
a lambda abstraction with a reducible body

weak head normal form:
an expression where the top level (head) isn't a redex

[Terei]

References : [1]

WHNF

[4]

evaluation strategies:
call-by-value: arguments evaluated before function entered (copied)
call-by-name: arguments passed unevaluated
call-by-need: arguments passed unevaluated but an expression is only evaluated once (sharing)

no-strict evaluation Vs. lazy evaluation:
non-strict: Includes both call-by-name and call-by-need, general term for evaluation strategies that don't evaluate arguments before entering a function
lazy evaluation: Specific type of non-strict evaluation. Uses call-by-need (for sharing).

[Terei]

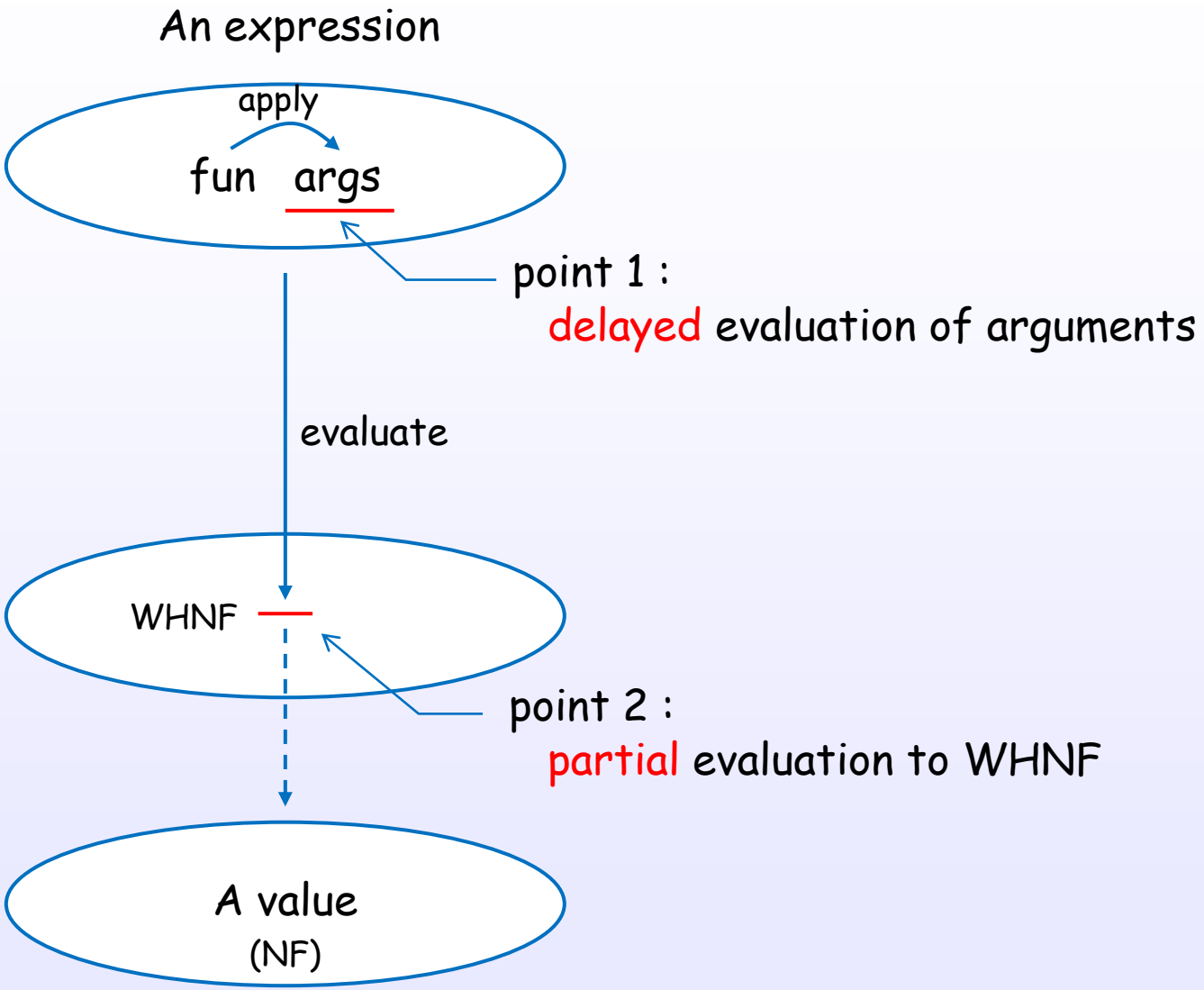
References : [1]

Thunk

References : [1]

Evaluation in Haskell

Key concept of Haskell's lazy evaluation



References : [1]

Pattern match

[CIS194]

References : [1]

Control the evaluation in Haskell

control

case pattern match

seq

deepseq

!

IO

References : [1]

Implementation in GHC

Tree, Graph

a expression

AST

Tree

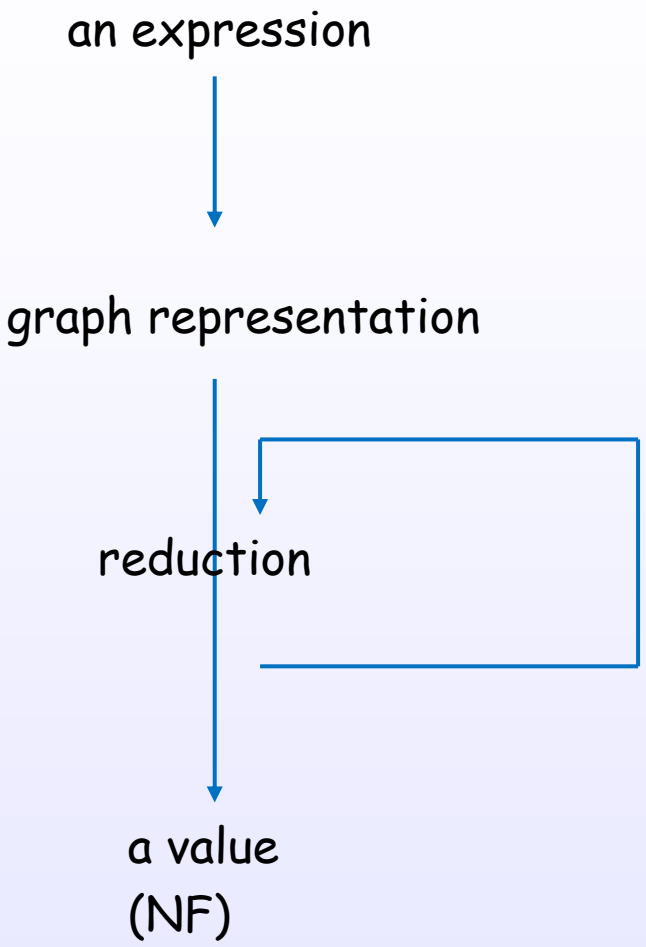
Graph

Shared Term

Lazy

References : [1]

evaluation, reduction



References : [1]

Expressions examples

References : [1]

STG heap objects

language	Just 5
implementation	heap object

References : [1]

Layer

Non-strictness $f \perp = \perp$

Lazy evaluation

Graph reduction

STG machine

References : [1]

Layer

Haskell semantics	take 5 [1..10]
internal representation	graph
STG semantics	heap object
STG machine	

References : [1]

Semantics

Bottom

domain

co-domain

defined

undefined

$f \perp = \perp$

[Bird, Chapter 2]

References : [1]

Strictness, Bottom

[Bird, Chapter 2]

References : [1]

References

References

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References

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