



# WebAssembly Spec Addendum: Legacy Exception Handling

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## 1 Introduction

This document describes an extension of the official WebAssembly standard developed by its [W3C Community Group](#)<sup>1</sup> with additional instructions for exception handling. These instructions were never standardized and are deprecated, but they may still be available in some engines, especially in web browsers.

## 2 Structure

### 2.1 Instructions

<sup>1</sup> <https://www.w3.org/community/webassembly/>

## Control Instructions

The set of recognised instructions is extended with the following:

```
instr ::= ...
| try blocktype instr* (catch tagidx instr*)* (catch_all instr*)? end
| try blocktype instr* delegate labelidx
| rethrow labelidx
```

The instructions `try` and `rethrow`, are concerned with exceptions. The `try` instruction installs an exception handler, and may either handle exceptions in the case of `catch` and `catch_all`, or rethrow them in an outer block in the case of `delegate`.

The `rethrow` instruction is only allowed inside a `catch` or `catch_all` clause and allows rethrowing the caught exception by lexically referring to a the corresponding `try`.

When `try-delegate` handles an exception, it also behaves similar to a forward jump, effectively rethrowing the caught exception right before the matching `end`.

## 3 Validation

### 3.1 Conventions

#### Contexts

The context is enriched with an additional flag on label types:

$$\begin{aligned} \text{labeltype} &::= \text{catch}^? \text{ resulttype} \\ C &::= \{\dots, \text{labels } \text{labeltype}^*, \dots\} \end{aligned}$$

Existing typing rules are adjusted as follows:

- All rules that extend the context with new labels use an absent catch flag.
- All rules that inspect the context for a label ignore the presence of a catch flag.

#### Note

This flag is used to distinguish labels bound by `catch` clauses, which can be targeted by `rethrow`.

### 3.2 Instructions

#### Control Instructions

`try blocktype instr1* (catch x instr2*)* (catch_all instr3)? end`

- The block type must be valid as some function type  $[t_1^*] \rightarrow [t_2^*]$ .
- Let  $C'$  be the same `context` as  $C$ , but with the `label type`  $[t_2^*]$  prepended to the labels vector.
- Under context  $C'$ , the instruction sequence  $instr_1^*$  must be valid with type  $[t_1^*] \rightarrow [t_2^*]$ .
- Let  $C''$  be the same `context` as  $C$ , but with the `label type` `catch`  $[t_2^*]$  prepended to the labels vector.
- For every  $x_i$  and  $instr_{2i}^*$  in  $(\text{catch } x \text{ } instr_{2i}^*)^*$ :
  - The tag  $C.\text{tags}[x_i]$  must be defined in the context  $C$ .
  - Let  $[t_{3i}^*] \rightarrow [t_{4i}^*]$  be the tag type  $C.\text{tags}[x_i]$ .
  - The result type  $[t_{4i}^*]$  must be empty.
  - Under context  $C''$ , the instruction sequence  $instr_{2i}^*$  must be valid with type  $[t_{3i}^*] \rightarrow [t_2^*]$ .
- If  $(\text{catch_all } instr_3^*)?$  is not empty, then:

- Under context  $C''$ , the instruction sequence  $instr_3^*$  must be valid with type  $[] \rightarrow [t_2^*]$ .
- Then the compound instruction is valid with type  $[t_1^*] \rightarrow [t_2^*]$ .

$$\frac{C \vdash blocktype : [t_1^*] \rightarrow [t_2^*] \quad C, \text{labels}[t_2^*] \vdash instr_1^* : [t_1^*] \rightarrow [t_2^*] \\ (C.\text{tags}[x] = [t^*] \rightarrow [])^* \\ C, \text{labels}(\text{catch } [t_2^*]) \vdash instr_2^* : [t^*] \rightarrow [t_2^*])^* \\ (C, \text{labels}(\text{catch } [t_2^*]) \vdash instr_3^* : [] \rightarrow [t_2^*])?}{C \vdash \text{try } blocktype \ instr_1^* (\text{catch } x \ instr_2^*)^* (\text{catch\_all } instr_3^*)? \text{ end} : [t_1^*] \rightarrow [t_2^*]}$$

#### Note

The notation  $C, \text{labels}(\text{catch } [t^*])$  inserts the new label type at index 0, shifting all others.

*try blocktype instr\* delegate l*

- The label  $C.\text{labels}[l]$  must be defined in the context.
- The block type must be valid as some function type  $[t_1^*] \rightarrow [t_2^*]$ .
- Let  $C'$  be the same [context](#) as  $C$ , but with the result type  $[t_2^*]$  prepended to the [labels](#) vector.
- Under context  $C'$ , the instruction sequence  $instr^*$  must be valid with type  $[t_1^*] \rightarrow [t_2^*]$ .
- Then the compound instruction is valid with type  $[t_1^*] \rightarrow [t_2^*]$ .

$$\frac{C \vdash blocktype : [t_1^*] \rightarrow [t_2^*] \quad C, \text{labels}[t_2^*] \vdash instr^* : [t_1^*] \rightarrow [t_2^*] \quad C.\text{labels}[l] = [t_0^*]}{C \vdash \text{try } blocktype \ instr^* \text{ delegate } l : [t_1^*] \rightarrow [t_2^*]}$$

#### Note

The label index space in the [context](#)  $C$  contains the most recent label first, so that  $C.\text{labels}[l]$  performs a relative lookup as expected.

*rethrow l*

- The label  $C.\text{labels}[l]$  must be defined in the context.
- Let  $(\text{catch}^? [t^*])$  be the [label type](#)  $C.\text{labels}[l]$ .
- The catch must be present in the [label type](#)  $C.\text{labels}[l]$ .
- Then the instruction is valid with type  $[t_1^*] \rightarrow [t_2^*]$ , for any sequences of value types  $t_1^*$  and  $t_2^*$ .

$$\frac{C.\text{labels}[l] = \text{catch } [t^*]}{C \vdash \text{rethrow } l : [t_1^*] \rightarrow [t_2^*]}$$

#### Note

The [rethrow](#) instruction is stack-polymorphic.

## 4 Execution

### 4.1 Runtime Structure

#### Stack

##### Exception Handlers

Legacy exception handlers are installed by try instructions. Instead of branch labels, their catch clauses have instruction blocks associated with them. Furthermore, a delegate handler is associated with a label index to implicitly rethrow to:

```
catch ::= ...
| catch tagidx instr*
| catch_all tagidx instr*
| delegate labelidx
```

#### Administrative Instructions

Administrative instructions are extended with the caught instruction that models exceptions caught by legacy exception handlers.

```
instr ::= ...
| caughtn{exnaddr} instr*
```

#### Block Contexts

Block contexts are extended to include caught instructions:

```
Bk ::= ...
| caughtn{exnaddr} Bk end
```

#### Throw Contexts

Throw contexts are also extended to include caught instructions:

```
T ::= ...
| caughtn{exnaddr} T end
```

### 4.2 Instructions

#### Control Instructions

```
try blocktype instr1* (catch x instr2*)* (catch_all instr3)? end
```

1. Assert: due to validation,  $\text{expand}_F(\text{blocktype})$  is defined.
2. Let  $[t_1^m] \rightarrow [t_2^n]$  be the function type  $\text{expand}_F(\text{blocktype})$ .
3. Let  $L$  be the label whose arity is  $n$  and whose continuation is the end of the try instruction.
4. Assert: due to validation, there are at least  $m$  values on the top of the stack.
5. Pop the values  $val^m$  from the stack.
6. Let  $F$  be the current frame.
7. For each catch clause ( $\text{catch } x_i \text{ instr}_{2i}^*$ ) do:
  - a. Assert: due to validation,  $F.\text{module}.\text{tagaddrs}[x_i]$  exists.
  - b. Let  $a_i$  be the tag address  $F.\text{module}.\text{tagaddrs}[x_i]$ .
  - c. Let  $\text{catch}_i$  be the catch clause ( $\text{catch } a_i \text{ instr}_{2i}^*$ ).

8. If there is a catch-all clause (`catch_all instr3*`), then:
  - a. Let  $catch'^?$  be the handler (`catch_all instr3*`).
9. Else:
  - a. Let  $catch'^?$  be empty.
10. Let  $catch^*$  be the concatenation of  $catch_i$  and  $catch'^?$ .
11. Enter the block  $val^m \ instr_1^*$  with label  $L$  and exception handler  $\text{handler}_n\{catch^*\}^*$ .

$$F; val^m (\text{try } bt \ instr_1^* (\text{catch } x \ instr_2^*)^* (\text{catch\_all } instr_3^*)? \text{ end}) \hookrightarrow \\ F; \text{label}_n\{\epsilon\} (\text{handler}_n\{(\text{catch } a_x \ instr_2^*)^* (\text{catch\_all } instr_3^*)?\} val^m \ instr_1^* \text{ end}) \text{ end} \\ (\text{if expand}_F(bt) = [t_1^m] \rightarrow [t_2^n] \wedge (F.\text{module}.tagaddrs[x] = a_x)^*))$$

`try blocktype instr* delegate l`

1. Assert: due to validation,  $\text{expand}_F(blocktype)$  is defined.
2. Let  $[t_1^m] \rightarrow [t_2^n]$  be the function type  $\text{expand}_F(blocktype)$ .
3. Let  $L$  be the label whose arity is  $n$  and whose continuation is the end of the try instruction.
4. Let  $H$  be the `exception handler`  $l$ , targeting the  $l$ -th surrounding block.
5. Assert: due to validation, there are at least  $m$  values on the top of the stack.
6. Pop the values  $val^m$  from the stack.
7. Enter the block  $val^m \ instr^*$  with label  $L$  and exception handler  $HANDLER_n\{DELEGATE-l\}$ .

$$F; val^m (\text{try } bt \ instr^* \text{ delegate } l) \hookrightarrow F; \text{label}_n\{\epsilon\} (\text{handler}_n\{\text{delegate } l\} val^m \ instr^* \text{ end}) \text{ end} \\ (\text{if expand}_F(bt) = [t_1^m] \rightarrow [t_2^n])$$

`throw_ref`

1. Let  $F$  be the current frame.
2. Assert: due to validation, a reference is on the top of the stack.
3. Pop the reference  $ref$  from the stack.
4. If  $ref$  is `ref.null ht`, then:
  - a. Trap.
5. Assert: due to validation,  $ref$  is an exception reference.
6. Let  $\text{ref.exn ea}$  be  $ref$ .
7. Assert: due to validation,  $S.\text{exns}[ea]$  exists.
8. Let  $exn$  be the exception instance  $S.\text{exns}[ea]$ .
9. Let  $a$  be the tag address  $exn.tag$ .
10. While the stack is not empty and the top of the stack is not an `exception handler`, do:
  - a. Pop the top element from the stack.
11. Assert: the stack is now either empty, or there is an exception handler on the top of the stack.
12. If the stack is empty, then:
  - a. Return the exception ( $\text{ref.exn } a$ ) as a result.
13. Assert: there is an `exception handler` on the top of the stack.
14. Pop the exception handler  $\text{handler}_n\{catch^*\}$  from the stack.

15. If  $catch^*$  is empty, then:

- a. Push the exception reference  $\text{ref.exn } ea$  back to the stack.
- b. Execute the instruction  $\text{throw\_ref}$  again.

16. Else:

- a. Let  $catch_1$  be the first catch clause in  $catch^*$  and  $catch'^*$  the remaining clauses.
- b. If  $catch_1$  is of the form  $\text{catch } x \ l$  and the exception address  $a$  equals  $F.\text{module.tagaddrs}[x]$ , then:
  - i. Push the values  $\text{exn.fields}$  to the stack.
  - ii. Execute the instruction  $\text{br } l$ .
- c. Else if  $catch_1$  is of the form  $\text{catch\_ref } x \ l$  and the exception address  $a$  equals  $F.\text{module.tagaddrs}[x]$ , then:
  - i. Push the values  $\text{exn.fields}$  to the stack.
  - ii. Push the exception reference  $\text{ref.exn } ea$  to the stack.
  - iii. Execute the instruction  $\text{br } l$ .
- d. Else if  $catch_1$  is of the form  $\text{catch\_all } l$ , then:
  - i. Execute the instruction  $\text{br } l$ .
- e. Else if  $catch_1$  is of the form  $\text{catch\_all\_ref } l$ , then:
  - i. Push the exception reference  $\text{ref.exn } ea$  to the stack.
  - ii. Execute the instruction  $\text{br } l$ .
- f. Else if  $catch_1$  is of the form  $\text{catch } x \ instr^*$  and the exception address  $a$  equals  $F.\text{module.tagaddrs}[x]$ , then:
  - i. Push the caught exception  $\text{caught}_n\{ea\}$  to the stack.
  - ii. Push the values  $\text{exn.fields}$  to the stack.
  - iii. Enter the catch block  $instr^*$ .
- g. Else if  $catch_1$  is of the form  $\text{catch\_all } instr^*$ , then:
  - i. Push the caught exception  $\text{caught}_n\{ea\}$  to the stack.
  - ii. Enter the catch block  $instr^*$ .
- h. Else if  $catch_1$  is of the form  $\text{delegate } l$ , then:
  - i. Assert: due to validation, the stack contains at least  $l$  labels.
  - ii. Repeat  $l$  times:
    - While the top of the stack is not a label, do:
      - Pop the top element from the stack.
  - iii. Assert: due to validation, the top of the stack now is a label.
  - iv. Pop the label from the stack.
  - v. Push the exception reference  $\text{ref.exn } ea$  back to the stack.
  - vi. Execute the instruction  $\text{throw\_ref}$  again.
- i. Else:
  1. Push the modified handler  $\text{handler}_n\{catch'^*\}$  back to the stack.
  2. Push the exception reference  $\text{ref.exn } ea$  back to the stack.
  3. Execute the instruction  $\text{throw\_ref}$  again.

$$\begin{aligned}
 \text{handler}_n\{( \text{catch } x \text{ instr}^* ) \text{ catch}^*\} T[(\text{ref.exn } a) \text{ throw\_ref}] \text{ end} &\xrightarrow{\dots} \text{caught}_n\{a\} \text{ exn.fields } \text{instr}^* \text{ end} \\
 &\quad (\text{if } \text{exn} = S.\text{exns}[a] \\
 &\quad \wedge \text{exn.tag} = F.\text{module.tagaddrs}[x]) \\
 \text{handler}_n\{( \text{catch\_all } \text{instr}^* ) \text{ catch}^*\} T[(\text{ref.exn } a) \text{ throw\_ref}] \text{ end} &\xrightarrow{\dots} \text{caught}_n\{a\} \text{ instr}^* \text{ end} \\
 B^l[\text{handler}_n\{(\text{delegate } l) \text{ catch}^*\} T[(\text{ref.exn } a) \text{ throw\_ref}] \text{ end}] &\xrightarrow{\dots} (\text{ref.exn } a) \text{ throw\_ref}
 \end{aligned}$$

`rethrow l`

1. Assert: due to validation, the stack contains at least  $l + 1$  labels.
2. Let  $L$  be the  $l$ -th label appearing on the stack, starting from the top and counting from zero.
3. Assert: due to validation,  $L$  is a catch label, i.e., a label of the form  $(\text{catch } [t^*])$ , which is a label followed by a caught exception in an active catch clause.
4. Let  $a$  be the caught exception address.
5. Push the value `ref.exn a` onto the stack.
6. Execute the instruction `throw_ref`.

$$\text{caught}_n\{a\} B^l[\text{rethrow } l] \text{ end} \xrightarrow{\dots} \text{caught}_n\{a\} B^l[(\text{ref.exn } a) \text{ throw\_ref}] \text{ end}$$

### Entering a catch block

1. Jump to the start of the instruction sequence  $\text{instr}^*$ .

### Exiting a catch block

When the end of a catch block is reached without a jump, thrown exception, or trap, then the following steps are performed.

1. Let  $\text{val}^m$  be the values on the top of the stack.
2. Pop the values  $\text{val}^m$  from the stack.
3. Assert: due to validation, a caught exception is now on the top of the stack.
4. Pop the caught exception from the stack.
5. Push  $\text{val}^m$  back to the stack.
6. Jump to the position after the end of the administrative instruction associated with the caught exception.

$$\text{caught}_n\{a\} \text{ val}^m \text{ end} \xrightarrow{\dots} \text{val}^m$$

#### Note

A caught exception can only be rethrown from the scope of the administrative instruction associated with it, i.e., from the scope of the catch or catch\_all block of a legacy try instruction. Upon exit from that block, the caught exception is discarded.

## 5 Binary Format

### 5.1 Instructions

## Control Instructions

```

instr ::= ...
| 0x06 bt:blocktype (in1:instr)*
  (0x07 x:tagidx (in2:instr)*)*
  (0x19 (in3:instr)?)? 0x0B      ⇒ try bt in1* (catch x in2)* (catch_all in3)? end
| 0x06 bt:blocktype (in:instr)*
  0x18 l:labelidx                  ⇒ try bt in* delegate l
| 0x09 l:labelidx                 ⇒ rethrow l

```

## 6 Text Format

### 6.1 Instructions

#### Control Instructions

The label identifier on a structured control instruction may optionally be repeated after the corresponding `end`, `else`, `catch`, `catch_all`, and `delegate` pseudo instructions, to indicate the matching delimiters.

```

blockinstrI ::= ...
| 'try' I':labelI bt:blocktype (in1:instrI')*
  ('catch' id1? x:tagidxI (in2:instrI'))*?
  ('catch_all' id1? (in3:instrI'))?
  'end' id2?                   ⇒ try bt in1* (catch x in2)* (catch_all in3)? end
  (if id1? = ε ∨ id1? = label, id2? = ε ∨ id2? = label)
| 'try' I':labelI bt:blocktype (in1:instrI')*
  'delegate' l:labelidxI l:labelidxI           ⇒ try bt in1* delegate l      (if id? = ε ∨ id? = label)
plaininstrI ::= ...
| 'rethrow' l:labelidxI      ⇒ rethrow l

```

## 7 Index of Instructions

Instruction	Binary Opcode	Type	Validation	Execution
try <i>bt</i>	0x06	[t <sub>1</sub> ]* → [t <sub>2</sub> ]	validation, validation	execution, execution
catch <i>x</i>	0x07		validation	execution
rethrow <i>n</i>	0x09	[t <sub>1</sub> ]* → [t <sub>2</sub> ]	validation	execution
delegate <i>l</i>	0x18		validation	execution
catch_all	0x19		validation	execution