



# 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](https://www.w3.org/community/webassembly/)<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

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

## Control Instructions

The set of recognised instructions is extended with the following:

$$\begin{array}{lcl} \text{instr} & ::= & \dots \\ & | & \text{try } \text{blocktype } \text{instr}^* (\text{catch } \text{tagidx } \text{instr}^*)^* (\text{catch\_all } \text{instr}^*)^? \text{ end} \\ & | & \text{try } \text{blocktype } \text{instr}^* \text{ delegate } \text{labelidx} \\ & | & \text{rethrow } \text{labelidx} \end{array}$$

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:

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

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

$\text{try } \text{blocktype } \text{instr}_1^* (\text{catch } x \text{ instr}_2^*)^* (\text{catch\_all } \text{instr}_3^*)^? \text{ end}$

- 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  $\text{instr}_1^*$  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  $\text{instr}_{2i}^*$  in  $(\text{catch } x \text{ instr}_2^*)^*$ :
  - 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  $\text{instr}_{2i}^*$  must be valid with type  $[t_{3i}^*] \rightarrow [t_2^*]$ .
- If  $(\text{catch\_all } \text{instr}_3^*)^?$  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  $[t_1^*] \rightarrow [t_2^*]$ .

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

#### Note

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

*try blocktype instr\* delegate l*

- The label  $C.labels[l]$  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  $[t_1^*] \rightarrow [t_2^*]$ .

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

#### Note

The label index space in the **context**  $C$  contains the most recent label first, so that  $C.labels[l]$  performs a relative lookup as expected.

*rethrow l*

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

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

#### 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:

$$\begin{array}{lcl} \text{catch} & ::= & \dots \\ & | & \text{catch } \text{tagidx } \text{instr}^* \\ & | & \text{catch\_all } \text{tagidx } \text{instr}^* \\ & | & \text{delegate } \text{labelidx} \end{array}$$

#### Administrative Instructions

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

$$\begin{array}{lcl} \text{instr} & ::= & \dots \\ & | & \text{caught}_n \{ \text{exnaddr} \} \text{instr}^* \text{ end} \end{array}$$

#### Block Contexts

Block contexts are extended to include caught instructions:

$$\begin{array}{lcl} B^k & ::= & \dots \\ & | & \text{caught}_n \{ \text{exnaddr} \} B^k \text{ end} \end{array}$$

#### Throw Contexts

Throw contexts are also extended to include caught instructions:

$$\begin{array}{lcl} T & ::= & \dots \\ & | & \text{caught}_n \{ \text{exnaddr} \} T \text{ end} \end{array}$$

### 4.2 Instructions

#### Control Instructions

try *blocktype* *instr*<sub>1</sub><sup>\*</sup> (catch *x* *instr*<sub>2</sub><sup>\*</sup>)<sup>\*</sup> (catch\_all *instr*<sub>3</sub><sup>\*</sup>)<sup>?</sup> 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  $\text{val}^m$  from the stack.
6. Let  $F$  be the current frame.
7. For each catch clause (catch  $x_i$  *instr*<sub>2*i*</sub><sup>\*</sup>) do:
  - a. Assert: due to [validation](#),  $F.\text{module.tagaddrs}[x_i]$  exists.
  - b. Let  $a_i$  be the tag address  $F.\text{module.tagaddrs}[x_i]$ .
  - c. Let  $\text{catch}_i$  be the catch clause (catch  $a_i$  *instr*<sub>2*i*</sub><sup>\*</sup>).

8. If there is a catch-all clause ( $\text{catch\_all } instr_3^*$ ), then:
  - a. Let  $catch'^{?}$  be the handler ( $\text{catch\_all } instr_3^*$ ).
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  $\text{handler}_n\{catch^*\}^*$ .

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

**try blocktype instr\* delegate l**

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. 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  $\text{HANDLER}_n\{\text{DELEGATE-}l\}$ .

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

**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  $\text{ref.null } ht$ , 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  $exn.\text{tag}$ .
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  $ref.exn\ ea$  back to the stack.
  - b. Execute the instruction  $throw\_ref$  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  $catch\ x\ l$  and the exception address  $a$  equals  $F.module.tagaddrs[x]$ , then:
    - i. Push the values  $exn.fields$  to the stack.
    - ii. Execute the instruction  $br\ l$ .
  - c. Else if  $catch_1$  is of the form  $catch\_ref\ x\ l$  and the exception address  $a$  equals  $F.module.tagaddrs[x]$ , then:
    - i. Push the values  $exn.fields$  to the stack.
    - ii. Push the exception reference  $ref.exn\ ea$  to the stack.
    - iii. Execute the instruction  $br\ l$ .
  - d. Else if  $catch_1$  is of the form  $catch\_all\ l$ , then:
    - i. Execute the instruction  $br\ l$ .
  - e. Else if  $catch_1$  is of the form  $catch\_all\_ref\ l$ , then:
    - i. Push the exception reference  $ref.exn\ ea$  to the stack.
    - ii. Execute the instruction  $br\ l$ .
  - f. Else if  $catch_1$  is of the form  $catch\ x\ instr^*$  and the exception address  $a$  equals  $F.module.tagaddrs[x]$ , then:
    - i. Push the caught exception  $caught_n\{ea\}$  to the stack.
    - ii. Push the values  $exn.fields$  to the stack.
    - iii. Enter the catch block  $instr^*$ .
  - g. Else if  $catch_1$  is of the form  $catch\_all\ instr^*$ , then:
    - i. Push the caught exception  $caught_n\{ea\}$  to the stack.
    - ii. Enter the catch block  $instr^*$ .
  - h. Else if  $catch_1$  is of the form  $delegate\ l$ , 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  $ref.exn\ ea$  back to the stack.
    - vi. Execute the instruction  $throw\_ref$  again.
  - i. Else:
    1. Push the modified handler  $handler_n\{catch'^*\}$  back to the stack.
    2. Push the exception reference  $ref.exn\ ea$  back to the stack.
    3. Execute the instruction  $throw\_ref$  again.

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

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 (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`.

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

## Entering a catch block

1. Jump to the start of the instruction sequence  $instr^*$ .

## 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  $val^m$  be the values on the top of the stack.
2. Pop the values  $val^m$  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  $val^m$  back to the stack.
6. Jump to the position after the end of the administrative instruction associated with the caught exception.

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

### 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          | $[t_1^*] \rightarrow [t_2^*]$ | validation, validation | execution, execution |
| catch <i>x</i>    | 0x07          |                               | validation             | execution            |
| rethrow <i>n</i>  | 0x09          | $[t_1^*] \rightarrow [t_2^*]$ | validation             | execution            |
| delegate <i>l</i> | 0x18          |                               | validation             | execution            |
| catch_all         | 0x19          |                               | validation             | execution            |