WebAssembly Specification Addendum: Legacy Exception Handling

Release 1.0

WebAssembly Community Group

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0.1 Introduction

This document describes an extension of the official WebAssembly standard developed by its W3C Community Group[1] 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.

0.2 Structure

0.2.1 Instructions

Control Instructions

The set of recognised instructions is extended with the following:

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

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.

0.3 Validation

0.3.1 Conventions

Contexts

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

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

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 an catch flag.

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

[1] https://www.w3.org/community/webassembly/

0.3.2 Instructions

Control Instructions

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

- The block type must be valid as some function type $[t_1^*] \to [t_2^*]$.
- 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 $[t_1^*] \to [t_2^*]$.
- Let C'' be the same context as C, but with the label type $\mathsf{catch}\ [t_2^*]$ prepended to the labels vector.
- For every x_i and instr_{2i}^* in $(\mathsf{catch}\ x\ \mathit{instr}_2^*)^*$:
  - The tag $C.\mathsf{tags}[x_i]$ must be defined in the context C.
  - Let $[t_{3i}^*] \to [t_{4i}^*]$ be the tag type $C.\mathsf{tags}[x_i]$.
  - The result type $[t_{4i}^*]$ must be empty.
  - Under context C'', the instruction sequence instr_{2i}^* must be valid with type $[t_{3i}^*] \to [t_2^*]$.
- If $(\mathsf{catch\_all}\ \mathit{instr}_3^*)^?$ is not empty, then:
  - Under context C'', the instruction sequence instr_3^* must be valid with type $[] \to [t_2^*]$.
- Then the compound instruction is valid with type $[t_1^*] \to [t_2^*]$.

$$\frac{\begin{array}{c}C \vdash \mathit{blocktype} : [t_1^*] \to [t_2^*] \qquad C, \mathsf{labels}\,[t_2^*] \vdash \mathit{instr}_1^* : [t_1^*] \to [t_2^*] \\ (C.\mathsf{tags}[x] = [t^*] \to [])^* \\ C, \mathsf{labels}\,(\mathsf{catch}\ [t_2^*]) \vdash \mathit{instr}_2^* : [t^*] \to [t_2^*])^* \\ (C, \mathsf{labels}\,(\mathsf{catch}\ [t_2^*]) \vdash \mathit{instr}_3^* : [] \to [t_2^*])^?\end{array}}{C \vdash \mathsf{try}\ \mathit{blocktype}\ \mathit{instr}_1^*\ (\mathsf{catch}\ x\ \mathit{instr}_2^*)^*\ (\mathsf{catch\_all}\ \mathit{instr}_3^*)^?\ \mathsf{end} : [t_1^*] \to [t_2^*]}$$

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

$\mathsf{try}\ \mathit{blocktype}\ \mathit{instr}^*\ \mathsf{delegate}\ l$

- The label $C.\mathsf{labels}[l]$ must be defined in the context.
- The block type must be valid as some function type $[t_1^*] \to [t_2^*]$.
- 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 $[t_1^*] \to [t_2^*]$.
- Then the compound instruction is valid with type $[t_1^*] \to [t_2^*]$.

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

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

rethrow l

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

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

Note: The rethrow instruction is stack-polymorphic.

0.4 Execution

0.4.1 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 rewthrow to:

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

Administrative Instructions

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

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

Block Contexts

Block contexts are extended to include caught instructions:

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

Throw Contexts

Throw contexts are also extended to include caught instructions:

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

0.4.2 Instructions

Control Instructions

$\mathsf{try}~blocktype~instr_1^*~(\mathsf{catch}~x~instr_2^*)^*~(\mathsf{catch\_all}~instr_3^*)^?~\mathsf{end}$

1. Assert: due to validation, $\mathrm{expand}_F(blocktype)$ is defined.
2. Let $[t_1^m] \to [t_2^n]$ be the function type $\mathrm{expand}_F(blocktype)$.
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 $(\mathsf{catch}~x_i~instr_{2i}^*)$ do:
   a. Assert: due to validation, $F.\mathsf{module}.\mathsf{tagaddrs}[x_i]$ exists.
   b. Let a_i be the tag address $F.\mathsf{module}.\mathsf{tagaddrs}[x_i]$.
   c. Let $catch_i$ be the catch clause $(\mathsf{catch}~a_i~instr_{2i}^*)$.
8. If there is a catch-all clause $(\mathsf{catch\_all}~instr_3^*)$, then:
   a. Let $catch'^?$ be the handler $(\mathsf{catch\_all}~instr_3^*)$.
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 $\mathsf{handler}_n\{catch^*\}^*$.

$$\begin{array}{l} F; val^m~(\mathsf{try}~bt~instr_1^*~(\mathsf{catch}~x~instr_2^*)^*~(\mathsf{catch\_all}~instr_3^*)^?~\mathsf{end} \quad \hookrightarrow \\ \qquad F; \mathsf{label}_n\{\epsilon\}~(\mathsf{handler}_n\{(\mathsf{catch}~a_x~instr_2^*)^*~(\mathsf{catch\_all}~instr_3^*)^?\}~val^m~instr_1^*~\mathsf{end})~\mathsf{end} \\ (\mathrm{if}~\mathrm{expand}_F(bt) = [t_1^m] \to [t_2^n] \wedge (F.\mathsf{module}.\mathsf{tagaddrs}[x] = a_x)^*) \end{array}$$

$\mathsf{try}~blocktype~instr^*~\mathsf{delegate}~l$

1. Assert: due to validation, $\mathrm{expand}_F(blocktype)$ is defined.
2. Let $[t_1^m] \to [t_2^n]$ be the function type $\mathrm{expand}_F(blocktype)$.
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}*.

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

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 ref.exn ea be ref.
7. Assert: due to validation, S.exns$[ea]$ exists.
8. Let exn be the exception instance S.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 (ref.exn a) as a result.
13. Assert: there is an exception handler on the top of the stack.
14. Pop the exception handler 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.

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

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.

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

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.

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

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.

0.5 Binary Format

0.5.1 Instructions

Control Instructions

$$\begin{array}{llll}
\mathtt{instr} & ::= & \dots & \\
& | & \mathtt{0x06}\ \ bt{:}\mathtt{blocktype}\ \ (in_1{:}\mathtt{instr})^*\ \ (\mathtt{0x07}\ \ x{:}\mathtt{tagidx}\ \ (in_2{:}\mathtt{instr})^*)^*\ \ (\mathtt{0x19}\ \ (in_3{:}\mathtt{instr})^*)^?\ \ \mathtt{0x0B} & \Rightarrow\ \ \mathtt{tr} \\
& | & \mathtt{0x06}\ \ bt{:}\mathtt{blocktype}\ \ (in{:}\mathtt{instr})^*\ \ \mathtt{0x18}\ \ l{:}\mathtt{labelidx} & \Rightarrow\ \ \mathtt{tr} \\
& | & \mathtt{0x09}\ \ l{:}\mathtt{labelidx} & \Rightarrow\ \ \mathtt{re}
\end{array}$$

0.6 Text Format

0.6.1 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.

$$
\begin{array}{llll}
\mathtt{blockinstr}_I & ::= & \dots & \\
& | & \text{`}\mathtt{try}\text{'}~I'{:}\mathtt{label}_I~bt{:}\mathtt{blocktype}~(in_1{:}\mathtt{instr}_{I'})^*~(\text{`}\mathtt{catch}\text{'}~\mathtt{id}_1^?~x{:}\mathtt{tagidx}_I~(in_2{:}\mathtt{instr}_{I'})^*)^* & \\
& & \qquad (\text{`}\mathtt{catch\_all}\text{'}~\mathtt{id}_1^?~(in_3{:}\mathtt{instr}_{I'})^*)^?~\text{`}\mathtt{end}\text{'}~\mathtt{id}_2^? & \\
& & \quad \Rightarrow \quad \mathsf{try}~bt~in_1^*~(\mathsf{catch}~x~in_2^*)^*~(\mathsf{catch\_all}~in_3^*)^?~\mathsf{end} & \\
& & \qquad (\mathrm{if}~\mathtt{id}_1^? = \epsilon \lor \mathtt{id}_1^? = \mathtt{label}, \mathtt{id}_2^? = \epsilon \lor \mathtt{id}_2^? = \mathtt{label}) & \\
& | & \text{`}\mathtt{try}\text{'}~I'{:}\mathtt{label}_I~bt{:}\mathtt{blocktype}~(in_1{:}\mathtt{instr}_{I'})^*~\text{`}\mathtt{delegate}\text{'}~l{:}\mathtt{labelidx}_I~l{:}\mathtt{labelidx}_I & \\
& & \quad \Rightarrow \quad \mathsf{try}~bt~in_1^*~\mathsf{delegate}~l \qquad (\mathrm{if}~\mathtt{id}^? = \epsilon \lor \mathtt{id}^? = \mathtt{label}) & \\
\mathtt{plaininstr}_I & ::= & \dots & \\
& | & \text{`}\mathtt{rethrow}\text{'}~l{:}\mathtt{labelidx}_I \quad \Rightarrow \quad \mathsf{rethrow}~l &
\end{array}
$$

0.7 Appendix

0.7.1 Index of Instructions

Instruction	Binary Opcode	Type	Validation	Execution
try bt	0x06	$[t_1^*] \to [t_2^*]$	validation, validation	execution, execution
catch x	0x07		validation	execution
rethrow n	0x09	$[t_1^*] \to [t_2^*]$	validation	execution
delegate l	0x18		validation	execution
catch_all	0x19		validation	execution

Note: Multi-byte opcodes are given with the shortest possible encoding in the table. However, what is following the first byte is actually a u32 with variable-length encoding and consequently has multiple possible representations.

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