WebAssembly Specification 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[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.

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

2 Structure

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.

3 Validation

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.

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 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 $(\mathsf{catch\_all}\ instr_3^*)^?$ 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 $[t_1^*] \to [t_2^*]$.

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

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

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

- 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 $[t_1^*] \to [t_2^*]$.

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

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.

$\mathsf{rethrow}\ l$

- 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 $[t_1^*] \to [t_2^*]$, for any sequences of value types t_1^* and t_2^*.

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

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 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:

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

4.2 Instructions

Control Instructions

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

1. Assert: due to validation, $\mathrm{expand}_F(\mathit{blocktype})$ is defined.
2. Let $[t_1^m] \to [t_2^n]$ be the function type $\mathrm{expand}_F(\mathit{blocktype})$.
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 (catch x_i $instr^*_{2i}$) do:
   a. Assert: due to validation, F.module.tagaddrs[x_i] exists.
   b. Let a_i be the tag address F.module.tagaddrs[x_i].
   c. Let $catch_i$ be the catch clause (catch a_i $instr^*_{2i}$).
8. If there is a catch-all clause (catch_all $instr^*_3$), then:
   a. Let $catch'^?$ be the handler (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 handler$_n\{catch^*\}^*$.

$$\begin{array}{l} F; val^m\ (\mathsf{try}\ bt\ instr^*_1\ (\mathsf{catch}\ x\ instr^*_2)^*\ (\mathsf{catch\_all}\ instr^*_3)^?\ \mathsf{end} \quad \hookrightarrow \\ \qquad F; \mathsf{label}_n\{\epsilon\}\ (\mathsf{handler}_n\{(\mathsf{catch}\ a_x\ instr^*_2)^*\ (\mathsf{catch\_all}\ instr^*_3)^?\}\ val^m\ instr^*_1\ \mathsf{end})\ \mathsf{end} \\ (\text{if } \mathrm{expand}_F(bt) = [t^m_1] \to [t^n_2] \wedge (F.\mathsf{module.tagaddrs}[x] = a_x)^*) \end{array}$$

try $blocktype$ $instr^*$ delegate l

1. Assert: due to validation, $\mathrm{expand}_F(blocktype)$ is defined.
2. Let $[t^m_1] \to [t^n_2]$ 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}*.

$$\begin{array}{lll} F; val^m\ (\mathsf{try}\ bt\ instr^*\ \mathsf{delegate}\ l) & \hookrightarrow & F; \mathsf{label}_n\{\epsilon\}\ (\mathsf{handler}_n\{\mathsf{delegate}\ l\}\ val^m\ instr^*\ \mathsf{end})\ \mathsf{end} \\ & & (\text{if } \mathrm{expand}_F(bt) = [t^m_1] \to [t^n_2]) \end{array}$$

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 $(\mathsf{ref.exn}\ a)$ as a result.
13. Assert: there is an exception handler on the top of the stack.
14. Pop the exception handler $\mathsf{handler}_n\{catch^*\}$ from the stack.
15. If $catch^*$ is empty, then:
    a. Push the exception reference $\mathsf{ref.exn}\ ea$ back to the stack.
    b. Execute the instruction $\mathsf{throw\_ref}$ 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 $\mathsf{catch}\ x\ l$ and the exception address a equals $F.\mathsf{module.tagaddrs}[x]$, then:
        i. Push the values $exn.\mathsf{fields}$ to the stack.
        ii. Execute the instruction $\mathsf{br}\ l$.
    c. Else if $catch_1$ is of the form $\mathsf{catch\_ref}\ x\ l$ and the exception address a equals $F.\mathsf{module.tagaddrs}[x]$, then:
        i. Push the values $exn.\mathsf{fields}$ to the stack.
        ii. Push the exception reference $\mathsf{ref.exn}\ ea$ to the stack.
        iii. Execute the instruction $\mathsf{br}\ l$.
    d. Else if $catch_1$ is of the form $\mathsf{catch\_all}\ l$, then:
        i. Execute the instruction $\mathsf{br}\ l$.
    e. Else if $catch_1$ is of the form $\mathsf{catch\_all\_ref}\ l$, then:
        i. Push the exception reference $\mathsf{ref.exn}\ ea$ to the stack.
        ii. Execute the instruction $\mathsf{br}\ l$.
    f. Else if $catch_1$ is of the form $\mathsf{catch}\ x\ instr^*$ and the exception address a equals $F.\mathsf{module.tagaddrs}[x]$, then:
        i. Push the caught exception $\mathsf{caught}_n\{ea\}$ to the stack.
        ii. Push the values $exn.\mathsf{fields}$ to the stack.
        iii. Enter the catch block $instr^*$.
    g. Else if $catch_1$ is of the form $\mathsf{catch\_all}\ instr^*$, then:
        i. Push the caught exception $\mathsf{caught}_n\{ea\}$ to the stack.
        ii. Enter the catch block $instr^*$.
    h. Else if $catch_1$ is of the form $\mathsf{delegate}\ l$, 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 $\mathsf{ref.exn}\ ea$ back to the stack.
        vi. Execute the instruction $\mathsf{throw\_ref}$ again.

i. Else:

1. Push the modified handler $\mathsf{handler}_n\{catch'^*\}$ back to the stack.
2. Push the exception reference $\mathsf{ref.exn}\ ea$ back to the stack.
3. Execute the instruction $\mathsf{throw\_ref}$ again.

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

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 $(\mathsf{catch}\ [t^*])$, 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 $\mathsf{ref.exn}\ a$ onto the stack.
6. Execute the instruction $\mathsf{throw\_ref}$.

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

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.

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5 Binary Format

5.1 Instructions

Control Instructions

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

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.

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

7 Appendix

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