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# NanoWasm Specification

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*NanoWasm* is a small language with simple types and instructions.



## ABSTRACT SYNTAX

The *abstract syntax* of types is as follows:

$$\begin{aligned} mut &::= \text{mut} \\ valtype &::= i32 \mid i64 \mid f32 \mid f64 \\ functype &::= valtype^* \rightarrow valtype^* \\ globaltype &::= mut^? valtype \end{aligned}$$

Instructions take the following form:

$$\begin{aligned} const &::= 0 \mid 1 \mid 2 \mid \dots \\ instr &::= \begin{array}{l} \text{nop} \\ | \\ \text{drop} \\ | \\ \text{select} \\ | \\ valtype.\text{const } const \\ | \\ \text{local.get } localidx \\ | \\ \text{local.set } localidx \\ | \\ \text{global.get } globalidx \\ | \\ \text{global.set } globalidx \end{array} \end{aligned}$$

The instruction `nop` does nothing, `drop` removes an operand from the stack, `select` picks one of two operands depending on a condition value. The instruction `t.const c` pushed the constant `c` to the stack. The remaining instructions access local and global variables.





## VALIDATION

NanoWasm instructions are *type-checked* under a context that assigns types to indices:

$$\text{context} ::= \{\text{globals } \text{globaltype}^*, \text{locals } \text{valtype}^*\}$$

### 2.1 nop

The `nop` instruction is valid with the  $\epsilon \rightarrow \epsilon$ .

$$\overline{C \vdash \text{nop} : \epsilon \rightarrow \epsilon}$$

### 2.2 drop

The `drop` instruction is valid with the  $t \rightarrow \epsilon$ .

$$\overline{C \vdash \text{drop} : t \rightarrow \epsilon}$$

### 2.3 select

The `select` instruction is valid with the  $t \text{ i32} \rightarrow t$ .

$$\overline{C \vdash \text{select} : t \text{ i32} \rightarrow t}$$

### 2.4 const

The `(t.const c)` instruction is valid with the  $\epsilon \rightarrow t$ .

$$\overline{C \vdash t.\text{const } c : \epsilon \rightarrow t}$$

### 2.5 local.get

The `(local.get x)` instruction is valid with the  $\epsilon \rightarrow t$  if:

- The  $C.\text{locals}[x]$  exists.
- The  $C.\text{locals}[x]$  is of the form  $t$ .

$$\frac{C.\text{locals}[x] = t}{C \vdash \text{local.get } x : \epsilon \rightarrow t}$$

## 2.6 local.set

The  $(\text{local.set } x)$   $(\text{local.set } x)$  is valid with the  $t \rightarrow \epsilon$   $t \rightarrow \epsilon$  if:

- The  $C.\text{locals}[x]$   $C.\text{locals}[x]$  exists.
- The  $C.\text{locals}[x]$   $C.\text{locals}[x]$  is of the form  $t$ .

$$\frac{C.\text{locals}[x] = t}{C \vdash \text{local.set } x : t \rightarrow \epsilon}$$

## 2.7 global.get

The  $(\text{global.get } x)$   $(\text{global.get } x)$  is valid with the  $\epsilon \rightarrow t$   $\epsilon \rightarrow t$  if:

- The  $C.\text{globals}[x]$   $C.\text{globals}[x]$  exists.
- The  $C.\text{globals}[x]$   $C.\text{globals}[x]$  is of the form  $(\text{mut}^? t)$ .

$$\frac{C.\text{globals}[x] = \text{mut}^? t}{C \vdash \text{global.get } x : \epsilon \rightarrow t}$$

## 2.8 global.set

The  $(\text{global.set } x)$   $(\text{global.set } x)$  is valid with the  $t \rightarrow \epsilon$   $t \rightarrow \epsilon$  if:

- The  $C.\text{globals}[x]$   $C.\text{globals}[x]$  exists.
- The  $C.\text{globals}[x]$   $C.\text{globals}[x]$  is of the form  $(\text{mut } t)$ .

$$\frac{C.\text{globals}[x] = \text{mut } t}{C \vdash \text{global.set } x : t \rightarrow \epsilon}$$

## EXECUTION

NanoWasm execution requires a suitable definition of state and configuration:

$$\begin{aligned} \text{addr} &::= 0 \mid 1 \mid 2 \mid \dots \\ \text{moduleinst} &::= \{\text{globals } \text{addr}^*\} \\ \text{val} &::= \text{const } \text{valtype } \text{const} \\ \text{store} &::= \{\text{globals } \text{val}^*\} \\ \text{frame} &::= \{\text{locals } \text{val}^*, \text{module } \text{moduleinst}\} \\ \text{state} &::= \text{store}; \text{frame} \\ \text{config} &::= \text{state}; \text{instr}^* \end{aligned}$$

We define the following auxiliary functions for accessing and updating the state:

$$\begin{aligned} \text{local}((s; f), x) &= f.\text{locals}[x] \\ \text{global}((s; f), x) &= s.\text{globals}[f.\text{module.globals}[x]] \\ \text{update}_{\text{local}}((s; f), x, v) &= s; f[.\text{locals}[x] = v] \\ \text{update}_{\text{global}}((s; f), x, v) &= s[\text{globals}[f.\text{module.globals}[x]] = v]; f \end{aligned}$$

With that, execution is defined as follows:

### 3.1 nop

1. Do nothing.

$$\text{nop} \hookrightarrow \epsilon$$

### 3.2 drop

1. Assert: Due to validation, a value is on the top of the stack.
2. Pop the value  $\text{val}$  from the stack.

$$\text{val drop} \hookrightarrow \epsilon$$

### 3.3 select

1. Assert: Due to validation, value type is on the top of the stack.
2. Pop the value (i32.const  $c$ ) from the stack.
3. Assert: Due to validation, a value is on the top of the stack.
4. Pop the value  $\text{val}_2$  from the stack.
5. Assert: Due to validation, a value is on the top of the stack.
6. Pop the value  $\text{val}_1$  from the stack.

7. If  $c \neq 0$ , then:

a. Push the value  $val_1$  to the stack.

8. Else:

a. Push the value  $val_2$  to the stack.

$$val_1 \ val_2 \ (i32.const \ c) \ select \ \hookrightarrow \ val_1 \ \text{if } c \neq 0$$

$$val_1 \ val_2 \ (i32.const \ c) \ select \ \hookrightarrow \ val_2 \ \text{otherwise}$$

### 3.4 local.get $x$

1. Let  $z$  be the current state.

2. Let  $val$  be  $local(z, x)$ .

3. Push the value  $val$  to the stack.

$$z; (local.get \ x) \ \hookrightarrow \ z; val \ \text{if } val = local(z, x)$$

### 3.5 local.set $x$

1. Assert: Due to validation, a value is on the top of the stack.

2. Pop the value  $val$  from the stack.

$$z; val \ (local.set \ x) \ \hookrightarrow \ z'; \epsilon \ \text{if } z' = update_{local}(z, x, val)$$

### 3.6 global.get $x$

1. Let  $z$  be the current state.

2. Let  $val$  be  $global(z, x)$ .

3. Push the value  $val$  to the stack.

$$z; (global.get \ x) \ \hookrightarrow \ z; val \ \text{if } val = global(z, x)$$

### 3.7 global.set $x$

1. Assert: Due to validation, a value is on the top of the stack.

2. Pop the value  $val$  from the stack.

$$z; val \ (global.set \ x) \ \hookrightarrow \ z'; \epsilon \ \text{if } z' = update_{global}(z, x, val)$$

## BINARY FORMAT

The following grammars define the binary representation of NanoWasm programs.

First, constants are represented in LEB format:

$$\begin{aligned}
 \text{byte} &::= b:0x00 \mid \dots \mid b:0xFF &\Rightarrow b \\
 u(N) &::= n:\text{byte} &\Rightarrow n &\quad \text{if } n < 2^7 \wedge n < 2^N \\
 &\mid n:\text{byte } m:u(N-7) &\Rightarrow 2^7 \cdot m + (n - 2^7) &\quad \text{if } n \geq 2^7 \wedge N > 7 \\
 u32 &::= n:u(32) &\Rightarrow n \\
 u64 &::= n:u(64) &\Rightarrow n \\
 f(N) &::= b*:\text{byte}^{N/8} &\Rightarrow \text{float}(N, b^*) \\
 f32 &::= p:f(32) &\Rightarrow p \\
 f64 &::= p:f(64) &\Rightarrow p
 \end{aligned}$$

Types are encoded as follows:

$$\begin{aligned}
 \text{valtype} &::= 0x7F &\Rightarrow i32 \\
 &\mid 0x7E &\Rightarrow i64 \\
 &\mid 0x7D &\Rightarrow f32 \\
 &\mid 0x7C &\Rightarrow f64 \\
 \text{mut} &::= 0x00 &\Rightarrow \epsilon \\
 &\mid 0x01 &\Rightarrow \text{mut} \\
 \text{globaltype} &::= t:\text{valtype } mut:\text{mut} &\Rightarrow mut \ t \\
 \text{resulttype} &::= n:u32 (t:\text{valtype})^n &\Rightarrow t^n \\
 \text{functype} &::= 0x60 \ t_1^*:\text{resulttype } t_2^*:\text{resulttype} &\Rightarrow t_1^* \rightarrow t_2^*
 \end{aligned}$$

Finally, instruction opcodes:

$$\begin{aligned}
 \text{globalidx} &::= x:u32 &\Rightarrow x \\
 \text{localidx} &::= x:u32 &\Rightarrow x \\
 \text{instr} &::= 0x01 &\Rightarrow \text{nop} \\
 &\mid 0x1A &\Rightarrow \text{drop} \\
 &\mid 0x1B &\Rightarrow \text{select} \\
 &\mid 0x20 \ x:\text{localidx} &\Rightarrow \text{local.get } x \\
 &\mid 0x21 \ x:\text{localidx} &\Rightarrow \text{local.set } x \\
 &\mid 0x23 \ x:\text{globalidx} &\Rightarrow \text{global.get } x \\
 &\mid 0x24 \ x:\text{globalidx} &\Rightarrow \text{global.set } x \\
 &\mid 0x41 \ n:u32 &\Rightarrow i32.\text{const } n \\
 &\mid 0x42 \ n:u64 &\Rightarrow i64.\text{const } n \\
 &\mid 0x43 \ p:f32 &\Rightarrow f32.\text{const } p \\
 &\mid 0x44 \ p:f64 &\Rightarrow f64.\text{const } p
 \end{aligned}$$