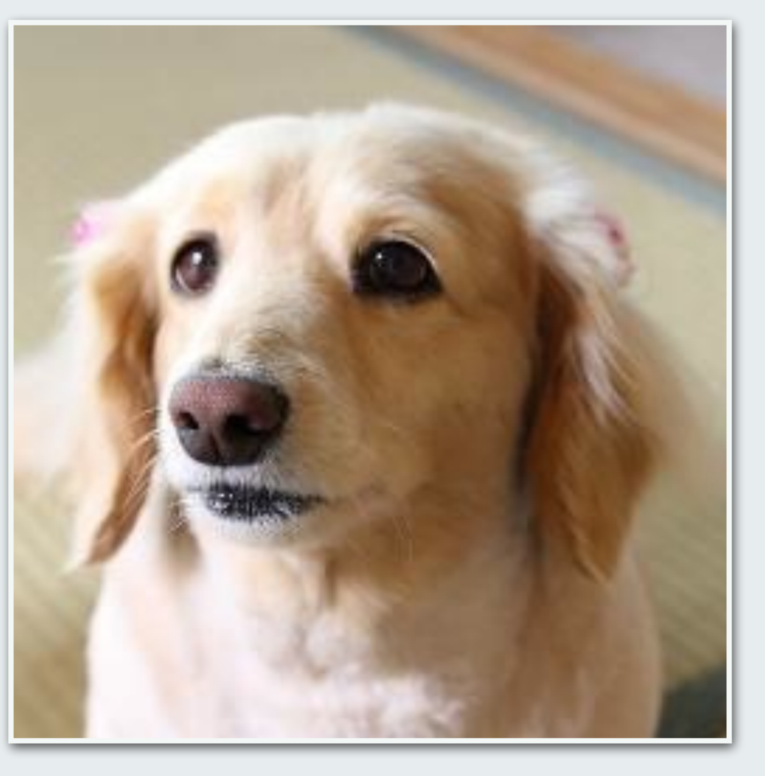
VimConf 2018 at Tokyo



- Loves programming tools such as programming languages or editors
- 70+ Vim plugins
  - clever-f.vimvim-clang-format, committia.vim, vim-grammarous etc)
  - Maintainer of filetype=wast
- Editor frontend such as NyaoVim, vim.wasm (Maintainer of Neovim Node.js binding)
- Creates my own language with LLVM

Today I'll talk about compiling Vim source codes into WebAssembly. Vim is working on browsers

ONLINE DEMO

https://rhysd.github.io/vim.wasm/

Agenda

- What's WebAssembly?
- Details of Implementation
- What is hard?
- Impressions and Future Works

What's WebAssembly (Wasm)?

WebAssembly (Wasm)

- New programming language running on browsers (on Stack-based VM)
- Programs are in binary format supposed to be compiled from other languages such as C, C++, Rust into Wasm
- Wasm language spec is defined by W3C as long-live web standard
- Comparing to JavaScript, Wasm is faster, memory efficient, file size efficient and safer
- Chrome, Firefox, Safari, Edge already support Wasm

- https://webassembly.org/
- https://developer.mozilla.org/docs/WebAssembly
- https://webassembly.github.io/spec/core/index.html#

WebAssembly (Wasm)

- Example: C source into Wasm (text format)

```c
#include <stdio.h>

int main(int argc, char ** argv) {
    puts("hello world\n");
}
```

hello.c

```
$ emcc -O3 -g hello.c
```

↑ compiling with emscripten

```
(module
 ;; ...

 (data (i32.const a) "hello world")

 ;; ...

 (func $_main (; 18 ;) (param $0 i32) (param $1 i32) (result i32)
  (drop
   (call $_puts
    (i32.const 1152)
   )
  )
  (i32.const 0)
 )
)
```

a.out.wast

- Wasm is supposed to be compiled from other languages, compiler toolchain is necessary
- emscripten: A toolchain to compile C, C++ sources into Wasm
    - Compiler&Linker: Build multiple C, C++ files into one Wasm file
    - Runtime: There are no malloc, IO, syscalls on browsers. Runtime libraries to shim them
    - Support interoperability between C, C++ and JavaScript. It enables to call functions from each other

```
# emcc: C compiler. Usage is similar to gcc
$ emcc -O3 hello.c -o hello.html

# Followings are generated
#   - hello.html (entry point. Open in browser)
#   - hello.js (JavaScript runtime)
#   - hello.wasm (Compilerd Wasm from hello.c containing _main() function)

$ python3 -m http.server 1234
$ open localhost:1234/hello.html
```

vim.wasm
Details of Implementation

What's vim.wasm?

A fork of Vim. Using emscripten, Vim's C sources are compiled into Wasm. It allows Vim to run on browsers

Only supports tiny features yet.

- Repository: https://github.com/rhysd/vim.wasm
- Japanese blog: https://rhysd.hatenablog.com/

What's vim.wasm?

All source code changes:

https://goo.gl/5WMW9n

https://github.com/rhysd/vim.wasm/compare/a9604e61451707b38fdcb088fbfaeea2b922fef6...f375d042138c824e3e149e0994b791248f2ecf41#files

Policy of implementation

- emscripten provides Unix-like runtime environment. But many things are missing on environment where Wasm is running.
  - Stdin is missing (stdout is connected to console.log)
  - Terminal screen is missing
    - Terminal library such as curses is missing
  - Wasm can't call DOM APIs (can't access to DOM elements)

Policy of implementation

- Implement Wasm Vim frontend as one of GUI frontends. Never run CUI Vim
- Use Core parts of Vim as-is (rendering process, input buffering, etcetc...)
- Create JavaScript runtime for doing what Wasm can't do. It collaborates with C functions
- To follow upstream changes, basically avoid breaking code changes by switching implementation with C preprocessor

Build: Fix autoconf settings

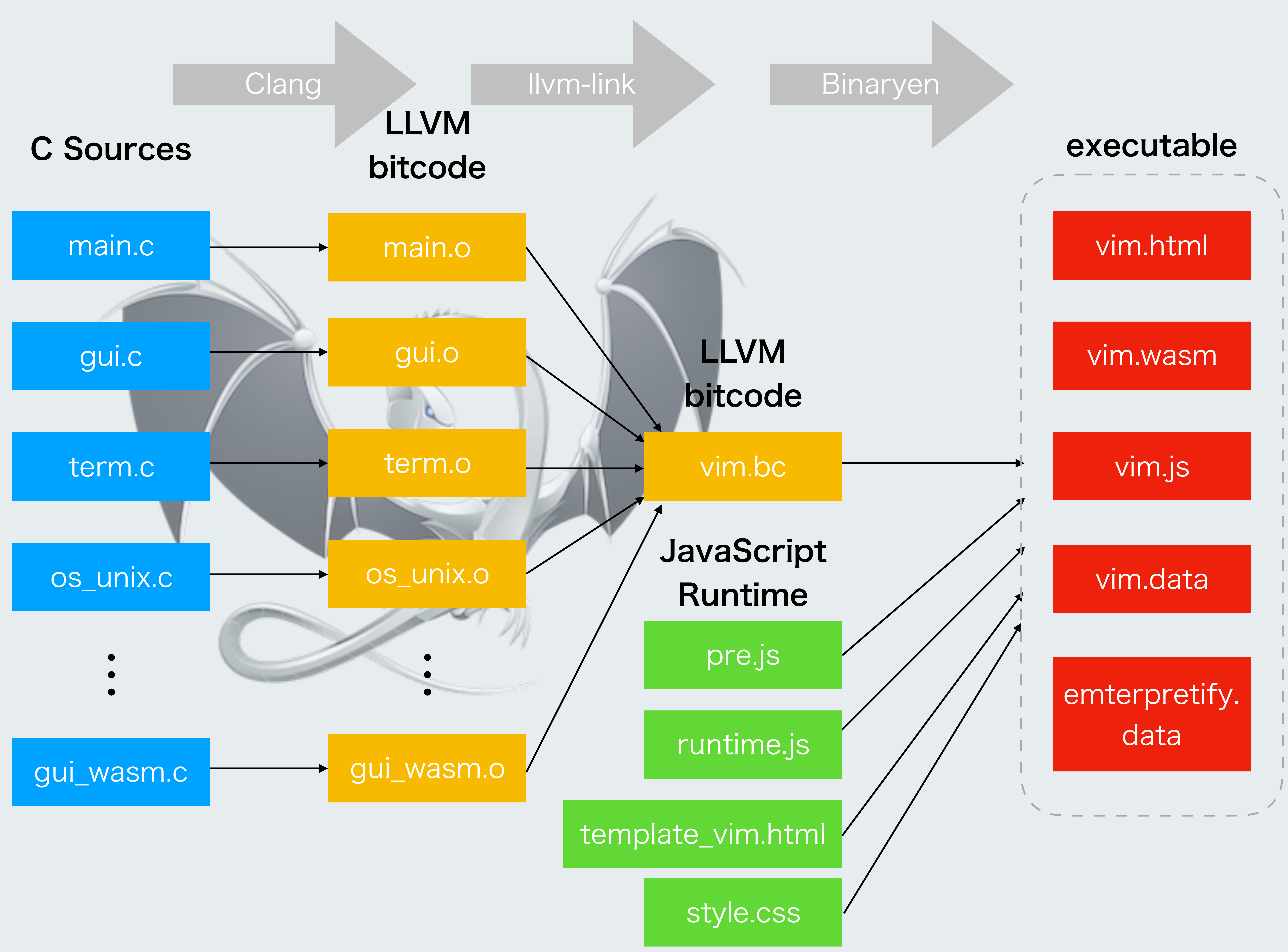
- Add variables such as $WASM_SRC to src/Makefile
- Add gui_wasm.c and other sources for Wasm to dependencies

```
WASM_SRC      = gui.c gui_wasm.c
WASM_OBJ      = objects/gui.o objects/gui_wasm.o
WASM_DEFS     = -DFEAT_GUI_WASM
WASM_IPATH    = -I. -Iproto
WASM_LIBS_DIR =
WASM_LIBS1    =
WASM_LIBS2    =
WASM_INSTALL = install_wasm
WASM_TARGETS =
WASM_MAN_TARGETS =
WASM_TESTTARGET =
WASM_BUNDLE =
WASM_TESTARG =

# ...

objects/gui_wasm.o: gui_wasm.c
    $(CCC) -o $@ gui_wasm.c
```

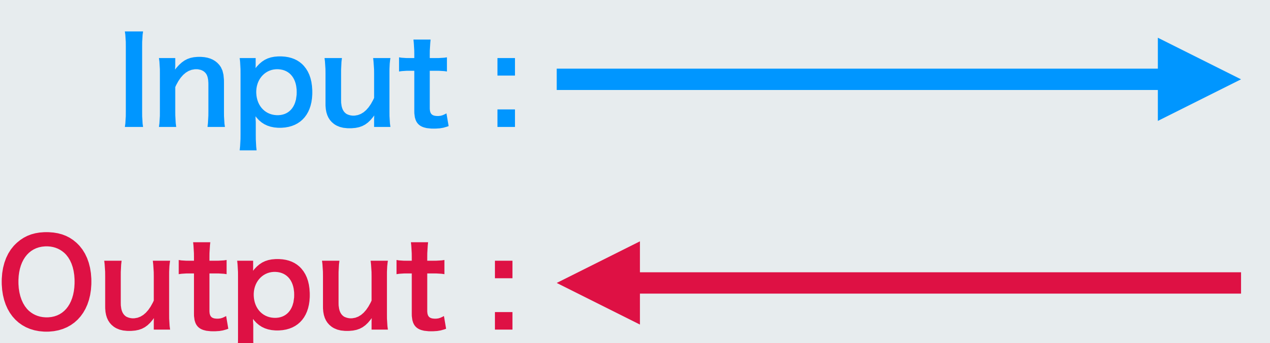
Build: Fix autoconf settings

- emconfigure, a wrapper script of ./configure, configures everything for emcc (C compiler of emscripten)
- To build minimal Vim, specify all `--disable-*` and `--with-features=tiny` on running ./configure
- ./configure fails at first. Repeat fixing src/auto/configure directly and trying again
    - e.g. Ignore terminal library check. It is mandatory for normal Vim but we don't need
- After configure passes, try `make` → It builds src/vim.bc

- https://kripken.github.io/emscripten-site/docs/compiling/Building-Projects.html


Clang
llvm-link
Binaryen
C Sources
LLVM bitcode
executable
main.c
gui.c
term.c
os_unix.c
gui_wasm.c
main.o
gui.o
term.o
os_unix.o
gui_wasm.o
LLVM bitcode
vim.bc
JavaScript Runtime
pre.js
runtime.js
template_vim.html
style.css
vim.html
vim.wasm
vim.js
vim.data
emterpretify.data

Overview of implementation



JavaScript

Calculate keycode of input char

Render to <canvas/>

Call C functions

Call JS functions

GUI Implementation in C

Calculate key sequence

Calculate how to render canvas

Keyboard event listener

Canvas API

Call rendering functions

add_to_input_buf()

vim.html

KeybaordEvent

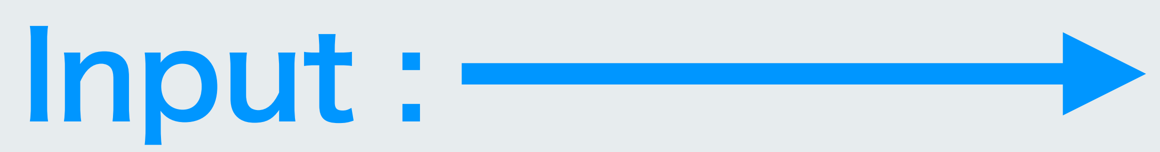
<canvas/>

Vim Core

Rendering events to screen happen

Add key sequence to input buffer

Overview of implementation



wasm/runtime.js

src/gui_wasm.c

wasm/vim.html

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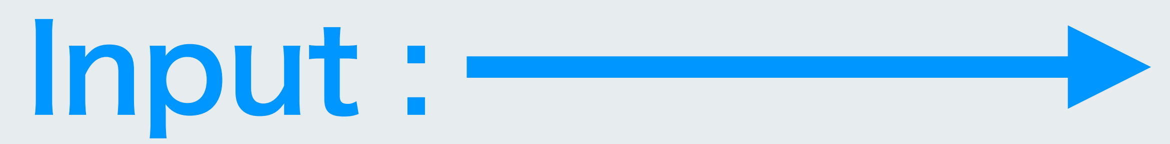
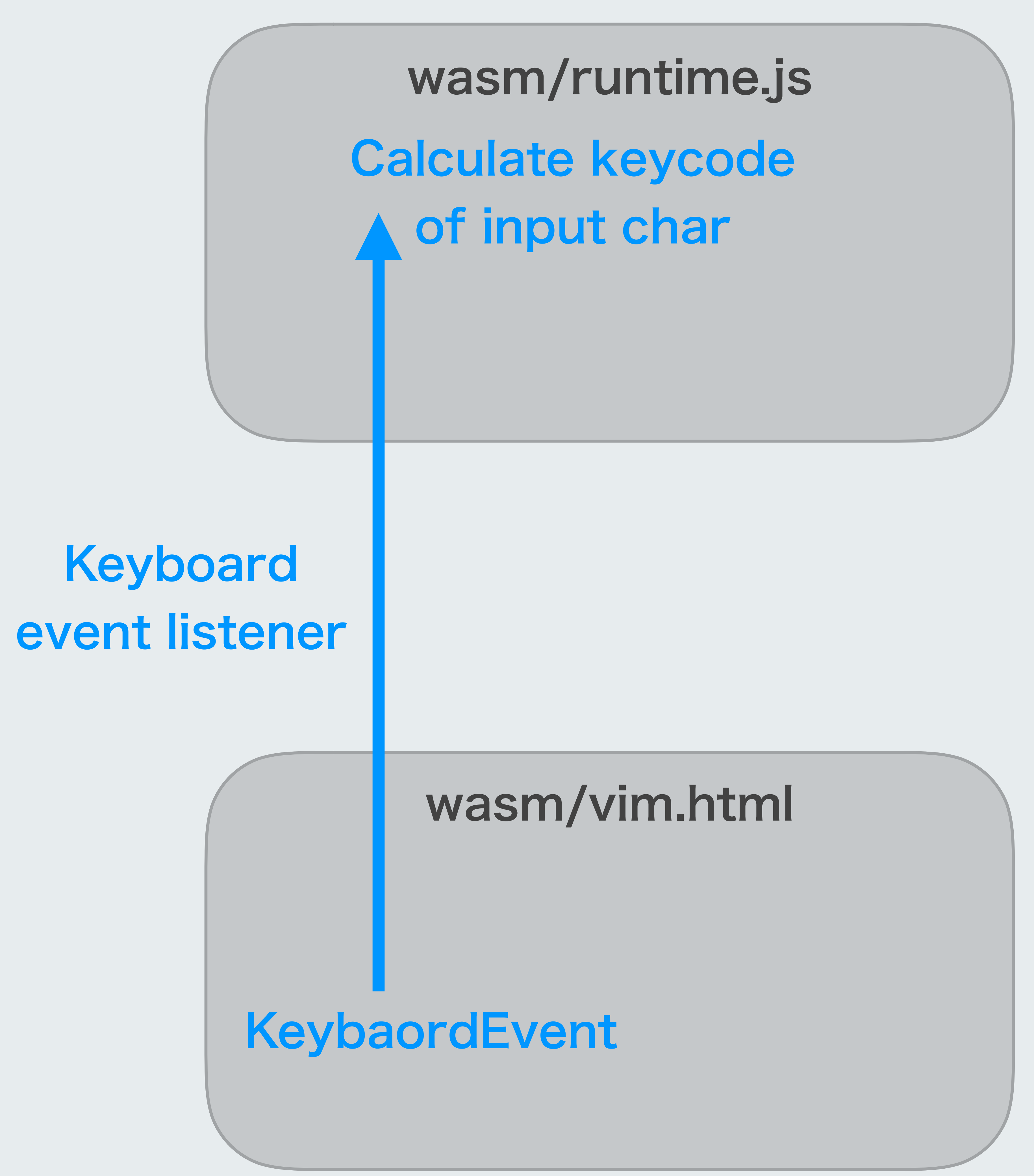
Overview of implementation

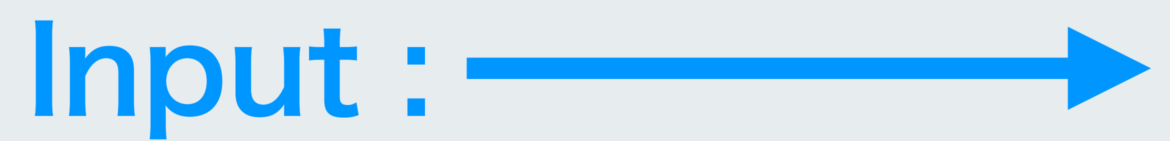




src/gui_wasm.c

Vim Core

Overview of implementation



wasm/runtime.js

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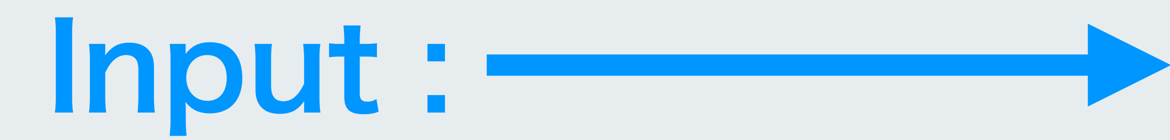

wasm/runtime.js

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Output :

wasm/runtime.js

src/gui_wasm.c

wasm/vim.html

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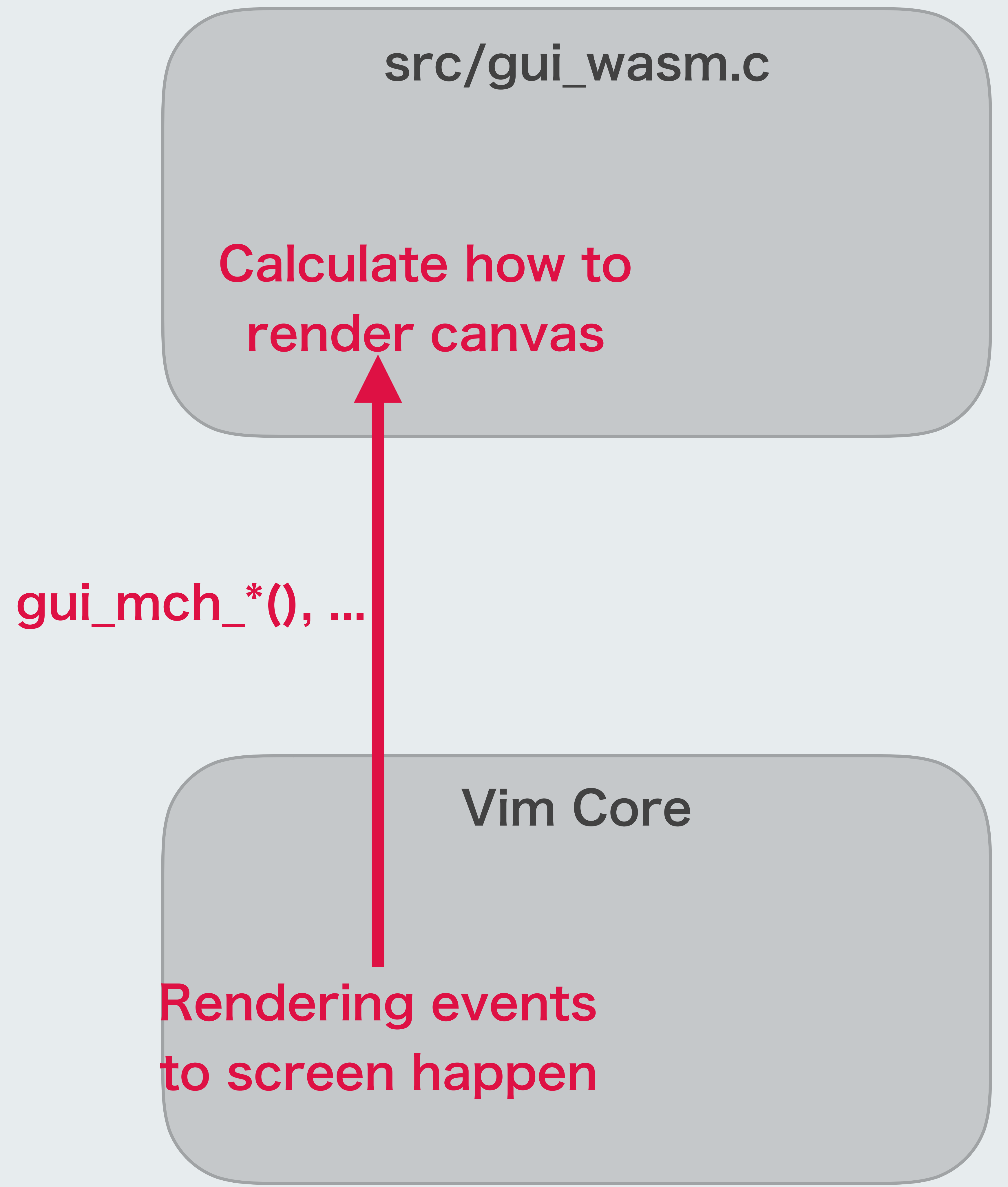

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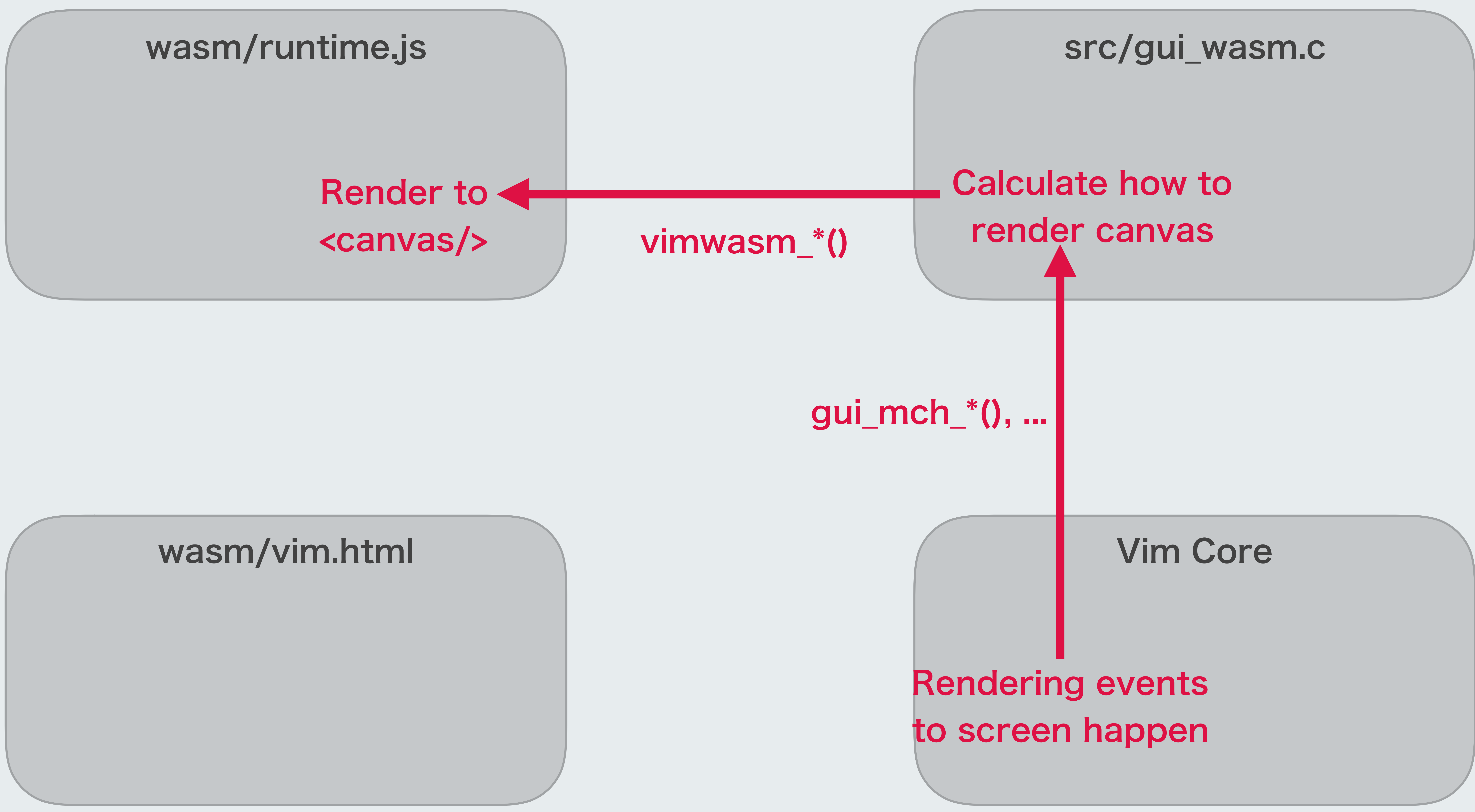

Overview of implementation

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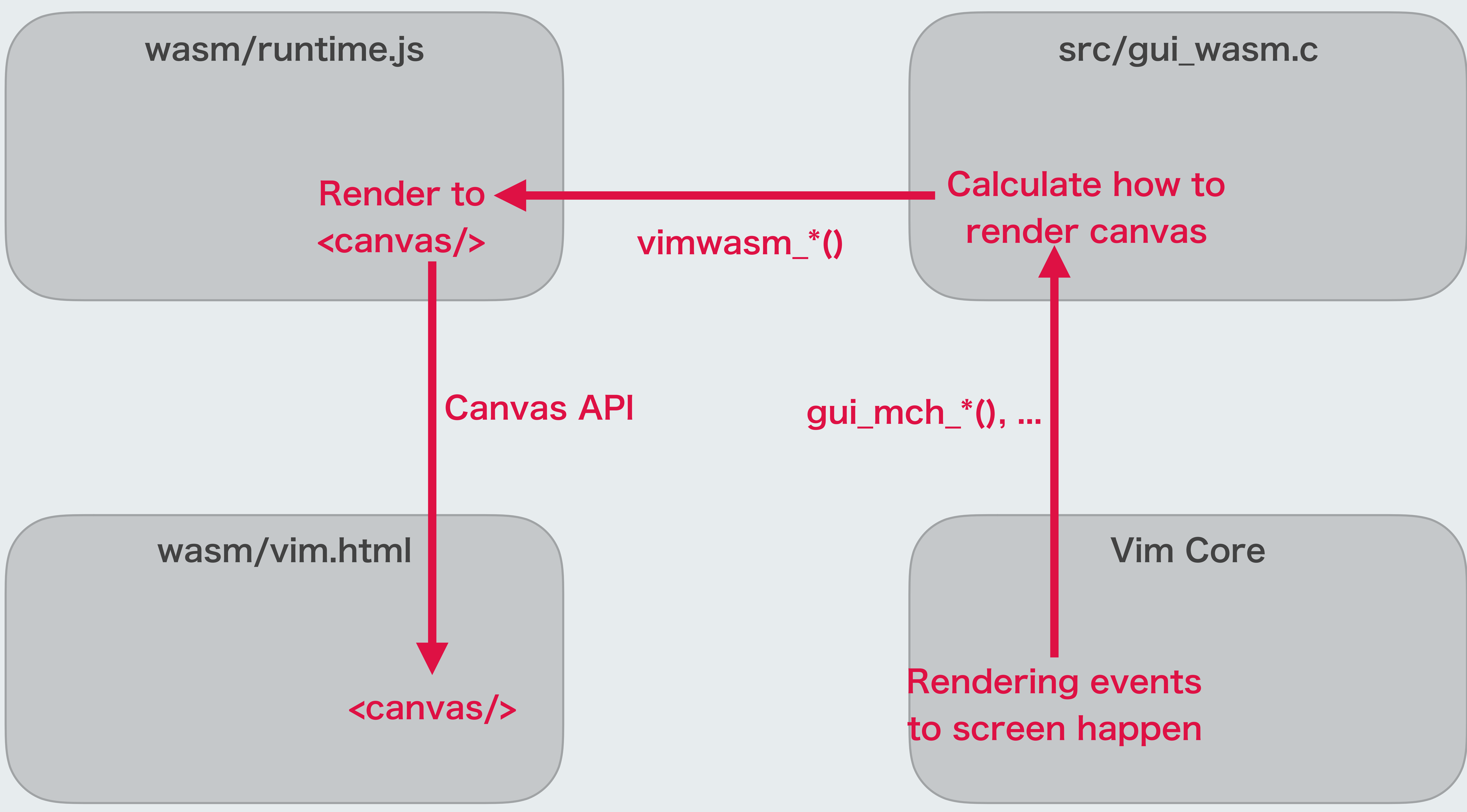

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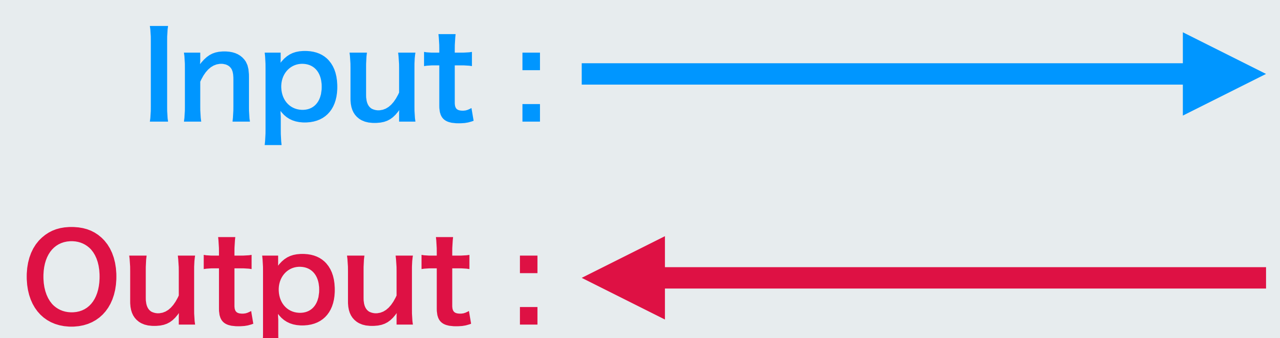

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GUI implementation of Vim

- Vim supports GTK, GNOME, MSWIN... Only one of them can be enabled at once. It can be determined at running ./configure
- GUI frontends are implemented in src/gui_*.{c,h} (and other files with C preprocessor)
- e.g. `--enable-gui=gtk3` compiles src/gui_gtk.c and gui_gtk.o will be linked (Other GUI implementations are ignored)

src/gui_*.c implementations

- Vim properly calls specific functions defined in gui_*.c
- gui_*.c implements the functions with GUI libraries/frameworks (rendering screen, wait for input from user, ...)
- Example of functions:

Function name	What should be done
gui_mch_init	Set default highlight colors, window size, ...
gui_mch_set_fg_color gui_mch_set_bg_color	Set current foreground/background colors
gui_mch_draw_string	Render a text at (row, col) with current foreground color
gui_mch_clear_block	Clear a rectangle (row1, col1, row2, col2) by painting the rectangle with tcurrent background color
gui_mch_delete_lines	Delete specified number of lines at specified row (and scroll up lines)
gui_wasm_resize_shell	Update screen size with specified rows and columns
gui_mch_wait_for_chars	Wait user's input by polling and blocking

gui_wasm.c : Rendering functions

The information to render things is passed via function parameters. Rendering functions in gui_wasm.c calculates how they are rendered on <canvas/>. And pass the result to JavaScript functions

Example: Clear rect (gui_mch_clear_block)

```c
// Clear Rectangle of left-top (row1, col1) to right-bottom (row2, col2)
void
gui_mch_clear_block(int row1, int col1, int row2, int col2)
{
    // Set default background color (gui.bg_color_code will also be set)
    gui_mch_set_bg_color(gui.back_pixel);

    // Vim handles rendering information with (row,col), but <canvas/> handles
    // cordinates (x,y). Translate (row,col) into (x,y)
    int x = gui.char_width * col1;
    int y = gui.char_height * row1;
    int w = gui.char_width * (col2 - col1 + 1);
    int h = gui.char_height * (row2 - row1 + 1);

    // <canvas/> handles colors with color code such as #123456
    char *color_code = gui.bg_color_code;
    int filled = TRUE;

    // Clear a block by painting a rectangle with background color
    //
    // vimwasm_* functions are declared, but not defined in C
    // Thanks to emscripten, it calls a function in JavaScript
    vimwasm_draw_rect(x, y, w, h, color_code, filled);
}
```

Example: Render a text (gui_mch_draw_string)

```
// s: text to render, len: length of text, flags: attributes of rendering
void
gui_mch_draw_string(int row, int col, char_u *s, int len, int flags)
{
    // Clear text region by background color if not transparent
    if (!(flags&DRAW_TRANSP)) {
        draw_rect(row, col, row, col + len - 1, gui.bg_color_code, TRUE);
    }

    // If the text only contains white spaces, don't need to render it
    // In the case return early...

    // Call JavaScript side function. Pass all information required to render the
text
    vimwasm_draw_text(
        gui.font_height,        // line height
        gui.char_height,        // character height
        gui.char_width,         // character width
        gui.char_width * col,   // x
        gui.char_height * row,  // y
        (char *)s,              // text
        len,                    // length of text
        flags&DRAW_BOLD,        // bold or not
        flags&DRAW_UNDERL,      // underline or not
        flags&DRAW_UNDERC,      // undercurl or not
        flags&DRAW_STRIKE);     // strikethrough or not
}
```

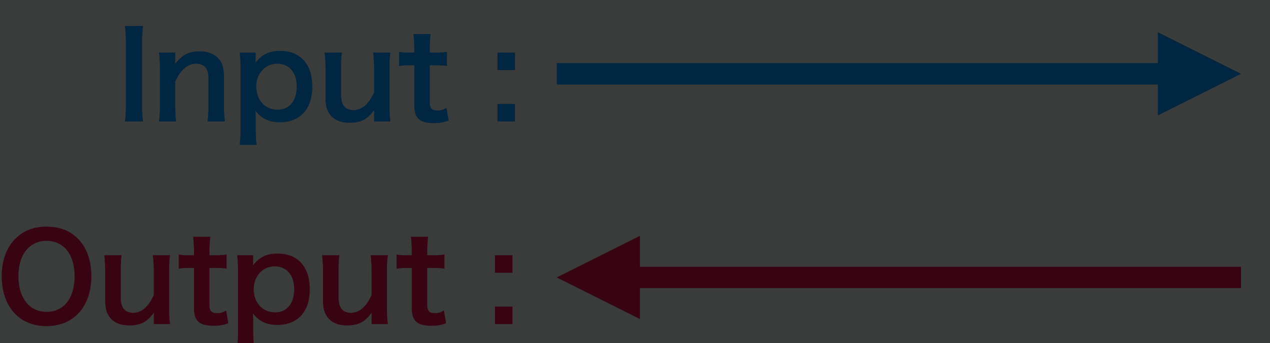
gui_wasm.c : Key input function

Key input is received by a browser.
JavaScript side sends the key input to C function (in Wasm). In C, calculate key input sequence and add it to Vim's input buffer

Example: Hanle key input (gui_wasm_send_key)

```c
// Function called by JavaScript on key input
//   - key_code: key code calculated in JavaScript
//   - special_code: Special code for special character such as arrow keys
//   - ctrl_key: Ctrl key is pressed or not
//   - shift_key: Shift key is pressed or not
//   - alt_key: Alt key is pressed or not
//   - meta_key: Meta (Cmd) key is pressed or not
void
gui_wasm_send_key(int key_code, int special_code, int ctrl_key, int shift_key, int alt_key, int meta_key)
{
    // Create a modifier keys mask with MOD_MASK_CTRL, MOD_MASK_SHIFT, ...
    // If special_code is non-zero, encode special code into key_code with TO_SPECIAL() macro...
    // If <C-c>, set interrupt flag...
    // Apply the modifier keys mask to key_code by extract_modifiers()...

    short len = 0; // Length of sequence
    char_u input[20]; // Actual input sequence

    // If any modifier key is pressed, add modifier key sequence at first...

    if (IS_SPECIAL(key_code)) {
        // Add key sequence for special codes...
    } else {
        input[len++] = key_code; // Add normal key to input sequence
    }

    // Add the input sequence into Vim's input buffer
    // Vim will pick up the inputs from the buffer and process them
    add_to_input_buf(input, len);
}
```

Overview of implementation



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vim.html

KeybaordEvent

<canvas/>

Vim Core

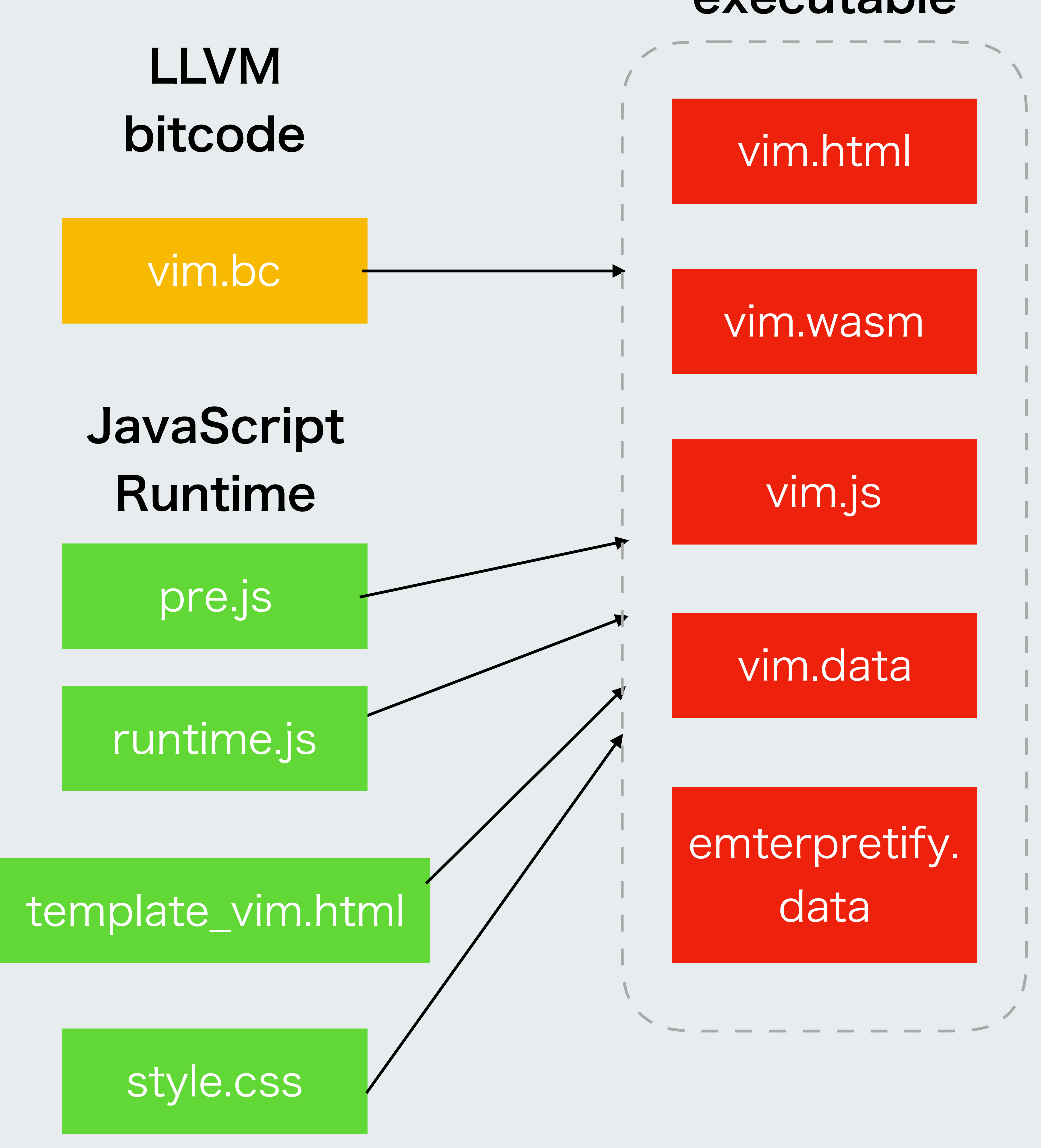
Rendering events to screen happen

Add key sequence to input buffer

JavaScript Runtime

- Define JavaScript functions to be called from C or to handle key input events in wasm/runtime.js
- Actual implementation is in TypeScript for maintenancability
- emscripten provides the way to create JavaScript library called from C

```
$ emcc --pre-js pre.js --js-library runtime.js
```

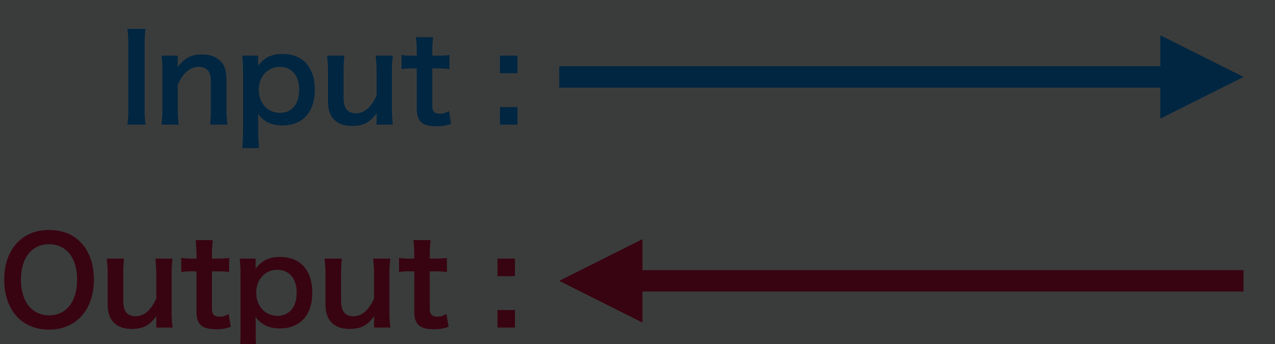


- https://kripken.github.io/emscripten-site/docs/porting/connecting_cpp_and_javascript/Interacting-with-code.html

Written in JavaScript. But this file is preprocessed by emcc to enable to call functions from C seamlessly

```
const VimWasmRuntime = {
    $VW__postset: 'VW.init()',
    $VW: {
        // init() is called on initialization.
        // Instanciate classes and keep them (e.g. VW.renderer)
        init() {
            class VimWindow { /* Window size management */ }

            class VimInput {
                onVimInit() {
                    // Create a wrapper function to be call C function gui_wasm_send_key()
                    const paramTypes = ['number', 'number', 'number', 'number', 'number', 'number'];
                    VimInput.prototype.sendKeyToVim = Module.cwrap('gui_wasm_send_key', null, paramTypes);
                }

                onKeydown(event) {
                    // Function called on keydown event.
                    // This calculates key code from KeyboardEvent and send it to C via VimInput.prototype.sendKeyToVim
                }
            }

            class CanvasRenderer { /* Class for <canvas/> rendering. Enque rendering events and handle them on animation frame */ }
        },
    },

    // Define functions called from C

    // void vimwasm_draw_text(int, int, int, int, int, char *, int, int, int, int, int);
    vimwasm_draw_text(charHeight, lineHeight, charWidth, x, y, str, len, bold, underline, undercurl, strike) {
        const text = Pointer_stringify(str, len); // Convert C pointer into JavaScript string
        VW.renderer.enqueue(VW.renderer.drawText, /*...*/); // Enque the rendering event into render queue
    },

    // Other functions called from C...
};
autoAddDeps(VimWasmRuntime, '$VW');
mergeInto(LibraryManager.library, VimWasmRuntime); // Register as JavaScript library via emscripten API
```

Overview of implementation



vim.html

- Entrypoint of this application. Users open with browser
- emcc will generate an HTML file from HTML template
- Give an HTML template file path to --shell-file option of emcc

```
<!doctype html>
<html lang="en-us">
  <head>
    <!-- Stylesheet to show screen in whole page -->
    <link rel="stylesheet" href="style.css" />
  </head>
  <body>
    <div id="vim-editor">
      <!-- Main screen -->
      <canvas id="vim-screen"></canvas>
      <!-- Cursor part render various shape cursors -->
      <canvas id="vim-cursor"></canvas>
      <!-- Input element to receive keydown event -->
      <input id="vim-input" autocomplete="off" autofocus/>
    </div>
    <script>
      // Initialize emscripten Module global variable
      var Module = {
        preRun: [],
        postRun: [],
        print: console.log,
        printErr: console.error,
      };
    </script>
    <!-- Loading script will be embedded here.It loads
         vim.js and call vim.wasm _main() function -->
    {{{ SCRIPT }}}
  </body>
</html>
```

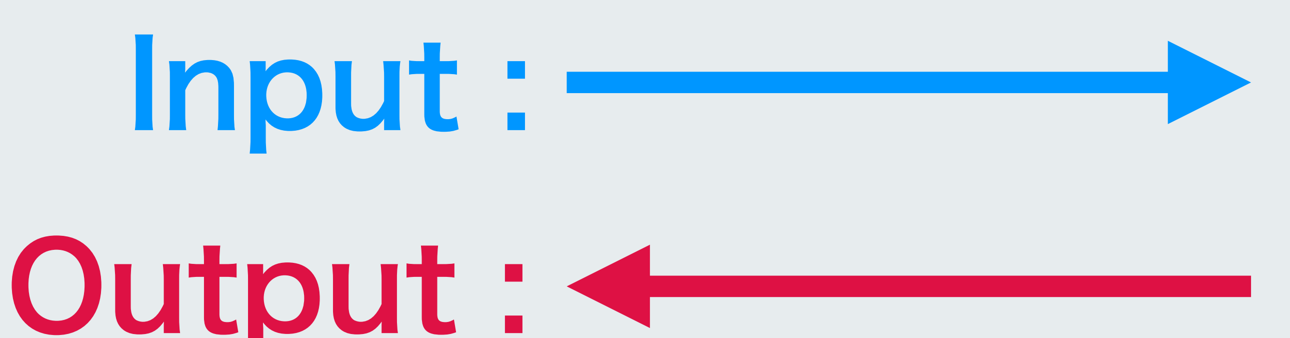
https://kripken.github.io/emscripten-site/docs/tools_reference/emcc.html

Files in runtime/*

- To reduce total file size, only minimal colorscheme, syntax files and vimrc are included
- emcc provides --preload-file option. It bundles all static files as one binary file
- Vim can access to files in /usr/local/share/vim via emscripten's FileSystem API as normal files. So no modification is needed for file access.

https://kripken.github.io/emscripten-site/docs/porting/files/packaging_files.html

Overview of implementation



wasm/runtime.js

Calculate keycode of input char

Render to <canvas/>

gui_wasm_send_key()

vimwasm_*()

src/gui_wasm.c

Calculate key sequence

Calculate how to render canvas

Keyboard event listener

Canvas API

gui_mch_*(), ...

add_to_input_buf()

wasm/vim.html

KeybaordEvent

<canvas/>

Vim Core

Rendering events to screen happen

Add key sequence to input buffer

main_loop()
normal.c
ui.c
getchar.c
gui_wasm.c
runtime.js
Browser
You
normal_cmd()
ui_inchar()
safe_vgetc()
gui_mch_wait_for_chars()
Input polling
input key
VimInput.onVimInput()
Dispatch
KeyboardEvent
gui_wasm_send_key()
Calculate
key code
Add key seq to
input buffer
add_to_input_buf()
Calculate key
sequence
input_available()
vim_is_input_buf_empty()
Process input
by Vim core
Call JS functions
e.g.
vimwasm_draw_text()
Call rendering functions
e.g. gui_mch_draw_string()
Enque event to
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On animation
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On animation
frame
Render to
<canvas/>
Display

vim.wasm
what is **hard**

Debugging is hard

- ~~Browser's DevTools don't fully support Wasm code debugging (e.g. breaking points)~~
  - Stepping over debugging (Chrome 70) and sourcemap (Chrome 71) will be supported! 🎉
- Only way to debug was printing. I added many logs to analyze bugs
  - In C: Output logs on debug build by switching by C preprocessor
  - In JavaScript: By switching an HTML files on debug/release build, they switch to enable/disable debug log
- <canvas/> is hard to debug since we can only see the rendered result image

Wasm can't sleep()

- Wasm is designed not to do blocking things the same as JavaScript. (If it's possible, it means blocking main thread)
- But the Vim main loop requires blocking wait to wait for user input in gui_*.c. (gui_mch_wait_for_chars() is expected to do input polling with input_available(). Polling requires sleep() to reduce CPU usage.

Somehow can we do sleep()?

- ~~Idea1: Busy loop~~ Busy loop in Wasm prevents keyboard event listeners being called. Key input does not work

- ~~Idea2: Calls sync~~ XHR and wait cache response in ServiceWorker Chrome does not support this due to bug. Firefox works but it causes high CPU usage of browser process.

Somehow can we do sleep()?

- emscripten's emscripten_sleep()
- By adding -s EMTERPRETIFY=1 to emcc, special function emscripten_sleep() will be available
- It works like normal sleep() function 🎉😭🎉

```
int
gui_mch_wait_for_chars(int wtime)
{
    int t = 0;
    int step = 10;
    while(1) {
        // Check input happened or not
        if (input_available()) {
            return OK;
        }

        t += step;

        // On timeout, return as failed
        if ((wtime >= 0) && (t >= wtime)) {
            return FAIL;
        }

        // Sleep 10ms to avoid high CPU usage!!
        emscripten_sleep(step);
    }
}
```

https://github.com/kripken/emscripten/wiki/Emterpreter

What's emscripten_sleep()

- But Wasm cannot block by design. How blocking function emscripten_sleep() is implemented? → Actually it does not block, but it *appears* to block
- Functions including emscripten_sleep() and functions calling them are compiled to Emterpreter byte codes, not wasm directly. The byte codes are executed by an interpreter called Emterpreter. (Other functions are compiled to Wasm as usual)
- Emterpreter is interpreter. So it can suspend execution and resume the execution after. Emterpreter suspends the execution of function at the call of emscripten_sleep(), stores the execution state, wait for duration asynchronously, and resumes the execution state to contue to run

https://github.com/kripken/emscripten/wiki/Emterpreter

emscripten_sleep()

- Explaining what happens by pseudo code (JavaScript).

C source

```c
printf("wait for 100ms\n");
int i = 42;

empscripten_sleep(100);

int j = i + 10;
printf("result=%d\n", j);
```

emcc transforms code on compilation

$ emcc -s EMTERPRETIFY=1

```javascript
// Actually emterpreter is run in Wasm and wait
// asynchronously in JavaScript. For explanation
// I wrote below code in JavaScript

emterpreter = new Emterpreter();

// Run codes before emscripten_sleep()
// on interpreter
emterpreter.run_code(`
    printf("wait for 100ms\n");
    int i = 42;
`);

// Suspend execution of interpreter
const state = emterpreter.suspend();

// Wait 100ms asynchronously with timer
setTimeout(function() {
    // Resume suspended execution state
    emterpreter.resume(state);

    // Run codes after emscripten_sleep()
    // on interpreter
    emterpreter.run_code(`
        int j = i + 10;
        printf("result=%d\n", j);
    `);
}, 100);
```

Problem: Emterpreter is Unsatable

- It makes compilation with emcc much slower for heavy code transformation
- Functions should be run with Emterpreter must be specified manually as option of emcc

```
-s 'EMTERPRETIFY_WHITELIST=["_gui_mch_wait_for_chars", "_flush_buffers", "_vgetorpeek_one", "_vgetorpeek", "_plain_vgetc", "_vgetc", "_safe_vgetc", "_normal_cmd", "_main_loop", "_inchar",
"_gui_inchar", "_ui_inchar", "_gui_wait_for_chars", "_gui_wait_for_chars_or_timer", "_vim_main2", "_main", "_gui_wasm_send_key", "_add_to_input_buf", "_simplify_key",
"_extract_modifiers", "_edit", "_invoke_edit", "_nv_edit", "_nv_colon", "_n_opencmd", "_nv_open", "_nv_search", "_fsync", "_mf_sync", "_ml_sync_all", "_updatescript", "_before_blocking",
"_getcmdline", "_getexline", "_do_cmdline", "_wait_return", "_op_change", "_do_pending_operator", "_get_literal", "_ins_ctrl_v", "_get_keystroke", "_do_more_prompt", "_msg_puts_display",
"_msg_puts_attr_len", "_msg_puts_attr", "_msg_putchar_attr", "_msg_putchar", "_list_in_columns", "_list_features", "_list_version", "_ex_version", "_do_one_cmd", "_msg_puts",
"_version_msg_wrap", "_version_msg", "_nv_g_cmd", "_do_sub"]'
```

- Emterpreter byte code is very redundant. It makes binary size bigger
- Passing strings from JavaScript functions to C functions which are run on Emterpreter causes crash. JS functions can't pass strings to C functions

vim.wasm
Impressions and Future Works

Impressions

- emscripten and Wasm implementation of browsers works fine
- 'tiny' feature is so helpful as start point of porting
- Without modifying core of Vim editor, only less than 7000 lines modifications enabled this porting. It only took 8days to see Vim works on browser at first!
- I learnt a log about Wasm toolchain and Vim's GUI implementation by this project

Future Works

- Implement Vim main loop without Emterpreter (trying in async-eventloop branch)
  - Vim main loop needs to be asynchronous (using emscripten main loop support)
  - It's hard to rewrite C sync function with async function with callbacks hell
    - e.g. int foo(char*) → void foo_async(char*, void (*)(int))
- Support small feature for syntax highlight and support mouse and IME
- Distribute vim.wasm as Web Component. People would be eble to use vim.wasm easily in browsers

- https://github.com/rhysd/vim.wasm/tree/async-eventloop
- https://kripken.github.io/emscripten-site/docs/porting/emscripten-runtime-environment.html#browser-main-loop