Structured Synchronous Reactive Programming for Game Development
Case Study: On Rewriting Pingus from C++ to CÉU

Francisco Sant'Anna
Departamento de Informática e Ciência da Computação, UERJ
francisco@ime.uerj.br

Figure 1: Pingus gameplay.

ABSTRACT

Abstract.

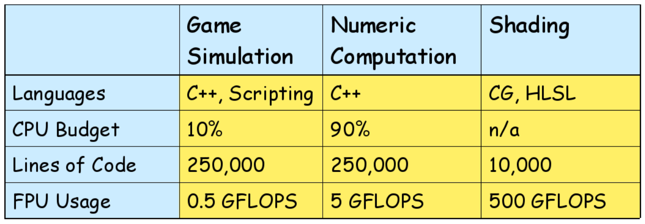
Keywords: Radiosity, global illumination, constant time.

1 INTRODUCTION

Pingus[1] is an open-source clone of Lemmings[2], a puzzle-platformer video game. The objective of the game is to guide a group of penguins through a number of obstacles towards a designated exit[3].

Pingus is developed in standard object-oriented C++, the *lingua franca* of game development [3]. The codebase is about 40.000 lines of code (LoCs)[4], divided into the engine, level editor, auxiliary libraries, and the game logic itself.

According to Tim Sweeney (of Unreal Engine fame), about half the complexity in game development resides in *simulation* (aka *game logic*), but which accounts for only 10% of the CPU budget [7]. The game logic "models the state of the game world as interacting objects evolve over time". The high development costs contrasting with the low impact on performance appeals for alternatives with productivity in mind, especially considering that it is the game logic that varies the most between projects. Sweeney states that "will gladly sacrifice 10% of our performance for 10% higher productivity".



	Game Simulation	Numeric Computation	Shading
Languages	C++, Scripting	C++	CG, HLSL
CPU Budget	10%	90%	n/a
Lines of Code	250,000	250,000	10,000
FPU Usage	0.5 GFLOPS	5 GFLOPS	500 GFLOPS

Figure 2: Three kinds of code [7].

Object-oriented games use the *observer pattern* [3] in the game logic to handle events from the environment (e.g., key presses and timers) and also as a notification mechanism between game entities. The observers are short-lived callbacks which must execute as fast as possible and in real time to keep the game reactive to incoming events. For this reason, callbacks cannot contain long-lasting locals and loops, which are elementary capabilities of classical structured programming [2, 4, 1]. In this sense, callbacks actually disrupt structured programming, becoming "our generation's `goto`".[5][6]

CÉU [6, 5] is a programming language that aims to offer a concurrent and expressive alternative to C/C++ with the characteristics that follow:

- *Reactive*: code only executes in reactions to events.
- *Structured*: programs use structured control mechanisms, such as `await` (to suspend a line of execution), and `par` (to combine multiple lines of execution).
- *Synchronous*: reactions run atomically and to completion on each line of execution, i.e., there's no implicit preemption or real parallelism.

Structured reactive programming eliminates callbacks, letting programmers write code in direct and sequential style and recover from the inversion of control imposed by the observer pattern [2]. CÉU supports logical parallelism with a resource-efficient implementation in terms of memory and CPU usage [6]. The runtime is single threaded and the language requires no garbage collection.

Contributions: - patterns - solutions

2 CONTROL-FLOW PATTERNS

The rewriting process consisted of identifying sets of callbacks implementing *control-flow behaviors* in the game and translating them to CÉU using appropriate structured constructs. As an example, a double mouse click is characterized by a first click, followed by a maximum amount of time, followed by a second click. This

[1]Pingus: `http://pingus.seul.org/`
[2]Lemmings: `https://en.wikipedia.org/wiki/Lemmings_(video_game)`
[3]Pingus gameplay: `https://www.youtube.com/watch?v=MKrJgIFtJX0`
[4]Pingus repository: `https://github.com/Pingus/pingus/tree/7b255840c201d028fd6b19a2185ccf7df3a2cd6e/src`
[5]"Callbacks as our Generations' Go To Statement": `http://tirania.org/blog/archive/2013/Aug-15.html`
[6]"Escape from Callback Hell": `http://elm-lang.org/learn/Escape-from-Callback-Hell.elm`

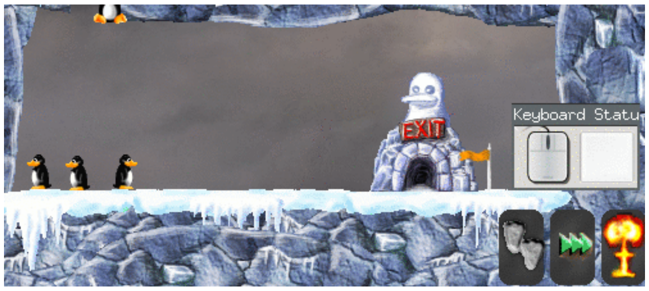


Figure 3: Double click detection.

behavior depends on different events (clicks and timers) which have to occur in a particular order. In C++, the implementation involves callbacks crossing reactions to successive events which manipulate state variables explicitly.

We can identify control-flow behaviors in C++ by looking for class members with identifiers resembling verbs, statuses, and counters (e.g., `pressed`, `particle_thrown`, `mode`, and `delay_count`). Good chances are that variables with these "suspicious names" encode some form of control-flow progression that cross multiple callback invocations.

We selected 9 representative game behaviors and describe their implementations in C++ and CÉU. We also categorized these examples in 5 abstract C++ control-flow patterns that likely apply to other games:

1. *Finite State Machines*: State machines describe the behavior of entities by mapping event occurrences to transitions between states that trigger appropriate actions.

2. *Continuation Passing*: The completion of a long-lasting activity may carry a continuation, i.e., some action to execute next.

3. *Dispatching Hierarchies*: Entities typically form a dispatching hierarchy in which a container that receives a stimulus automatically forwards it to its managed children.

4. *Lifespan Hierarchies*: Entities typically form a lifespan hierarchy in which a terminating container entity automatically destroys its managed children.

5. *Signaling Mechanisms*: Entities often need to communicate explicitly through signaling mechanisms, especially if there is no hierarchy relationship between them.

2.1 Finite State Machines Case Study: The Armageddon Button Double Click

State machines describe the behavior of entities by mapping event occurrences to transitions between states that trigger appropriate actions.

In Pingus, a double click in the *Armageddon* button at the bottom right of the screen literally explodes all pingus (Figure 3). Figure **??** compares the implementations in C++ and CÉU.

In C++, the class `ArmageddonButton` implements methods for rendering the button and handling mouse and timer events. The listing focus on the double click detection, hiding unrelated parts with <...>. The methods `update` (ln. 14–26) and `on_click` (ln. 28–34) are examples of *short-lived callbacks*, which are pieces of code that execute atomically in reaction to external input events. The callback `on_click` reacts to mouse clicks detected by the button base class `RectComponent` (ln. 2), while the callback `update` continuously reacts to the passage of time, frame by frame. Callbacks are short lived because they must react to input as fast as possible to let other callbacks execute, keeping the game with real-time responsiveness. The class first initializes the variable `pressed` to track the first click (ln. 3,32). It also initializes the variable `press_time` to count the time since the first click (ln. 4, 17). If another click occurs within 1 second, the class signals the double click to the application (ln. 30). Otherwise, the `pressed` and `press_time` state variables are reset (ln. 19–20). Figure 5 illustrates how we can model the double-click behavior in C++ as a state machine. The circles represent the state of the variables in the class, while the arrows represent the callbacks manipulating state. Note in the code how the accesses to the state variables are spread across the entire class. For instance, the distance between the initialization of `pressed` (ln. 3) and the last access to it (ln. 32) is over 40 lines in the original file. Arguably, this dispersion of code across methods makes the understanding and maintenance of the double-click behavior more difficult. Also, even though the state variables are private, unrelated methods such as `draw`‘, which is defined in middle of the class (ln. 10–12), can potentially access them.

CÉU provides structured constructs to deal with events, aiming to eradicate explicit manipulation of state variables for control-flow purposes. The loop detection (ln. 4–10) awaits the first click (ln. 5) and then, while watching 1 second (ln. 6–9), awaits the second click (ln. 7). If the second click occurs within 1 second, the `break` terminates the loop (ln. 8) and the `emit` signals the double click to the application (ln. 12). Otherwise, the `watching` block as a whole aborts and restarts the loop, falling back to the first click `await` (ln. 5). Double click detection in CÉU doesn't require state variables and is entirely self-contained in the `loop` body (ln. 4–10). Furthermore, these 7 lines of code *only* detect the double click, leaving the actual effect to happen outside the loop (ln. 12).

2.2 Continuation Passing Case Study: Advancing Pages in the Story Screen

The completion of a long-lasting activity may carry a continuation, i.e., some action to execute next.

The clickable *blue dots* in the campaign world map transit to ambience story screens (Figure 13). A story is composed of multiple pages and, inside each page, the words of the story appear incrementally over time. A first click in the button >>> fast forwards the words to show the full page. A second click advances to the next page, until the story terminates. If the page completes before a click (due to the time elapsing), a first click advances to the next page.

In C++, the class `StoryScreenComponent` implements the method `next_text`, which is a callback for clicks in >>>. The variable ‘pages‘ (ln. 4–5, 24–26) is a vector holding each page, but which also encodes *continuations* for the story progress: each call to `next_text` that advances the story (ln. 23–32) removes the current page (ln. 24) and sets the next action to perform (i.e., "display a new page") in the variable `current_page` (ln. 26). Figure 13 illustrates the continuation mechanism to advance pages and also a state machine for fast forwarding words (inside the dashed rectangle). The state variable `displayed` (ln. 6,15,20,21,27) switches between the behaviors "advancing text" and "advancing pages", which are both handled intermixed inside the method `next_text`.

The code in CÉU uses the internal event `next_text`, which is emitted from clicks in >>>. The sequential navigation from page to page uses a loop in direct style (ln. 6–15) instead of explicit state variables for the continuation and state machine. While the text advances in an inner loop (hidden in ln. 9), we watch the `next_text` event that fast forwards it. The loop may also eventually terminate with the time elapsing normally. This way, we do not need a variable (such as ‘displayed‘ in C++) to switch between the states "advancing text" and "advancing pages". The `par/or` makes the page advance logic to execute in parallel with the redrawing code (ln. 13). Whenever the page advances, the redrawing code is au-

```
ArmageddonButton::ArmageddonButton(<...>):
    RectComponent(<...>),
    pressed(false); // button initially not pressed
    press_time(0);    // how long since 1st click?
    <...>
{
    <...>
}

void ArmageddonButton::draw (<...>) {
    <...>
}

void ArmageddonButton::update (float delta) {
    <...>
    if (pressed) {
        press_time += delta;
        if (press_time > 1.0f) {
            pressed = false; // give up, 1st click
            press_time = 0;  // was too long ago
        }
    } else {
        <...>
        press_time = 0;
    }
}

void ArmageddonButton::on_click (<...>) {
    if (pressed) {
        server->send_armageddon_event();
    } else {
        pressed = true;
    }
}
```

[a] Implementation in C++

```
do
    var& RectComponent c = <...>;
    <...>
    loop do
        await c.component.on_click;
        watching 1s do
            await c.component.on_click;
            break;
        end
    end
    <...>
    emit outer.game.go_armageddon;
end
.
```

[b] Implementation in CÉU

Figure 4: Shared-memory concurrency in CÉU: example [a] is safe because the trails access x atomically in different reactions; example [b] is unsafe because both trails access y in the same reaction.

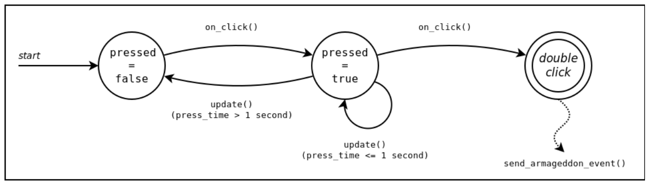


Figure 5: State machine for the *Armageddon* double click.

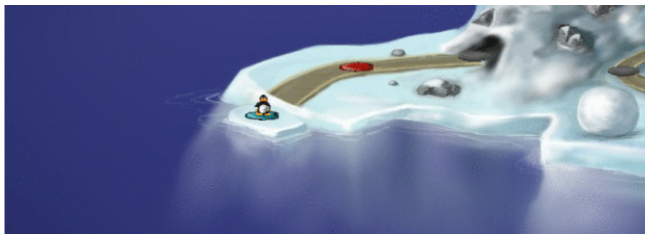


Figure 6: The Story screen.

tomatically aborted (due to the `or` modifier). The `await next_text` in sequence (ln. 11) is the condition to advance to the next page. Note that, unlike the implementation in C++, the "advancing text" behavior is not intermixed with the "advancing pages" behavior, instead, it is encapsulated inside the inner loop nested with a deeper indentation (ln. 9).

2.3 Dispatching Hierarchies Case Study: Bomber 'draw' and 'update' callbacks

Entities typically form a dispatching hierarchy in which a container that receives a stimulus automatically forwards it to its managed children.

In C++, the class `Bomber` declares a `sprite` member to handle its animation frames (Figure **??**). The `Sprite` class is part of the game engine and knows how to update and render itself. However, the `Bomber` still has to respond to `update` and `draw` requests from the game and forward them to the sprite (ln. 11–13 and 15–18). To understand how the `update` callback flows from the original environment stimulus from the game down to the sprite, we need to follow a long chain of 7 method dispatches (Figure 11):

1. `ScreenManager::display` in the main game loop calls `update`.
2. `ScreenManager::update` calls `last_screen->update` for the active game screen (a `GameSession` instance, considering the `Bomber`).
3. `GameSession::update` calls `world->update`.
4. `World::update` calls `obj->update` for each object in the world.
5. `PinguHolder::update` calls `pingu->update` for each pingu alive.
6. `Pingu::update` calls `action->update` for the active pingu action.
7. `Bomber::update` calls `sprite.update`. `Sprite::update` finally updates the animation frame.

Each dispatching step in the chain is necessary considering the game architecture:

- With a single assignment to `last_screen`, we can easily deactivate the current screen and redirect all dispatches to a new screen.
- The `World` class manages and dispatches events to all game entities, such as all pingus and traps, with the common interface `WorldObj`.
- Since it is common to iterate only over the pingus (vs. all world objects), the container `PinguHolder` manages all pingus.
- Since a single pingu can change between actions during lifetime, the `action` member decouples them with another level of indirection.
- Sprites are part of the game engine and are reusable everywhere (e.g., UI buttons, world objects, etc.), so it is also convenient to decouple them from actions.

The `draw` callback flows through the same dispatching hierarchy until reaching the `Sprite` class.

In CÉU, the `Bomber` action spawns a `Sprite` animation instance on its body. The `Sprite` instance (ln. 3) can react directly to external `dt` and `redraw` events (which are analogous to `update` and `redraw` callbacks, respectively), bypassing the program hierarchy entirely. While and *only while* the bomber abstraction is alive, the sprite animation is also alive. The radical decoupling between the program hierarchy and reactions to events eliminates dispatching chains entirely.

2.4 Lifespan Hierarchies Case Study: The Pingus Container

Entities typically form a lifespan hierarchy in which a terminating container entity automatically destroys its managed children.

In C++, the class `PinguHolder` is a container that holds all pingus alive. The method `PinguHolder::create_pingu` (ln. 1–6) is called periodically to create a new `Pingu` and add it to the `pingus` collection (ln. 3–4). The method `PinguHolder::update` (ln. 8–18) checks the state of all pingus on every frame, removing those with the dead status (ln. 12–14). Entities with dynamic lifespan in C++ require explicit `add` and `remove` calls associated to a container (ln. 4,13). Without the `erase` call above, a dead pingu would remain in the collection with updates on every frame (ln. 11). Since the `redraw` behavior for a dead pingu is innocuous, the death could go unnoticed but the program would keep consuming memory and CPU time. This problem is known as the *lapsed listener* [**?**] and also occurs in languages with garbage collection: A container typically holds a strong reference to a child (sometimes the only reference to it), and the runtime cannot magically detect it as garbage.

CÉU supports `pool` declarations to hold dynamic abstraction instances. Additionally, the `spawn` statement supports a pool identifier to associate the new instance with a pool. The game screen spawns a new `Pingu` on every invocation of `Pingu_Spawn`. The `spawn` statement (ln. 6) specifies the pool declared at the top-level block of the game screen (ln. 3). In this case, the lifespan of the new instances follows the scope of the pool (ln. 1–9) instead of the enclosing scope of the `spawn` statement (ln. 4–7). Since pools are also subject to lexical scope, the lifespan of all dynamically allocated pingus is constrained to the game screen. Lexical scopes handle memory and event dispatching automatically for static instances and also for pools. However, the lifespan of a dynamic instance does not necessarily have to match the lifespan of its associated pool (Figure 14). In CÉU, when the execution block of a dynamic instance terminates, which characterizes its *natural termination*, the instance is automatically removed from its pool. Therefore, dynamic instances do not require any extra bookkeeping related to containers or explicit deallocation. To remove a pingu from the game in CÉU, we just need to terminate its execution block according to the appropriate conditions: The `escape` statement (ln. TODO) aborts the execution block of the `Pingu` instance, removing it from its associated pool

```
StoryScreenComponent::StoryScreenComponent (<...>) :
    <...>
{
    pages        = <...>; // vector with loaded pages
    current_page = pages.back(); // first loaded page
    displayed    = false; // if current is complete
    <...>
}

<...>   // draw page over time

void StoryScreenComponent::update (<...>) {
    <...>
    if (&lt;all-words-appearing&gt;) {
        displayed = true;
    }
}

void StoryScreenComponent::next_text() {
    if (!displayed) {
        displayed = true;
        <...>     // remove current page
    } else {
        pages.pop_back();
        if (!pages.empty()) { // next page
            current_page = pages.back();
            displayed    = false;
            <...>
        } else {
            <...> // terminates the story screen
        }
    }
}
```

[a] Implementation in C++

```
code/await Story (void) -> bool do
    <...>
    event void next_text; // clicks in >>>

    { pages = <...>; } // same as in C++
    loop i in [0 <- {pages.size()}[ do
        par/or do
            watching next_text do
                <...> // advance text
            end
            await next_text;
        with
            <...> // redraw _pages[i]
        end
    end
end

















.
```

[b] Implementation in CÉU

Figure 7: Shared-memory concurrency in CÉU: example [a] is safe because the trails access x atomically in different reactions; example [b] is unsafe because both trails access y in the same reaction.

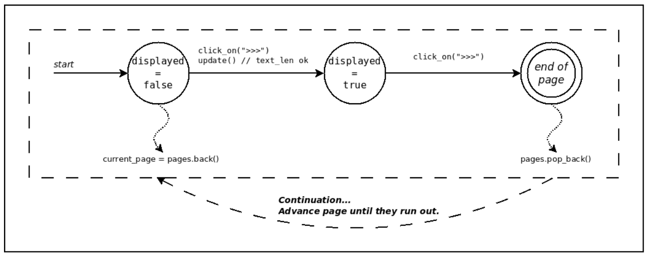


Figure 8: State machine for the Story screen.

automatically. Hence, a dynamic instance that terminates naturally leaves no traces in the program.

2.5 Signaling Mechanisms Case Study: Global Keys and the Options Menu

Entities often need to communicate explicitly through signaling mechanisms, especially if there is no hierarchy relationship between them.

The *Mouse Grab* option restricts the mouse movement to the game window boundaries (Figure 15). The option can be set anywhere in the game by pressing *Ctrl-G*. In addition, the *Options* menu has a check box to toggle the *Mouse Grab* option with mouse clicks while still responding to *Ctrl-G* presses.

The implementations in C++ and CÉU use a signalling mechanism to connect the key presses, the check box, and a configuration manager that applies the appropriate side effects in the game (i.e., restrict the mouse movement). Figure 16 illustrates how the mutual notifications create a dependency cycle between the configuration manager and the check box.

In C++, the class ‘GlobalEvent‘ detects *Ctrl-G* presses and invokes the callback ‘config_manager.set_mouse_grab‘: The class ‘ConfigManager‘ uses a ‘boost::signal‘ [[![X]][boost_signal]] to notify the application when the new configuration is applied: The ‘if‘ enclosing the signal emission @NN(if_1,-,if_2) breaks the dependency cycle of Figure 16 and prevents an infinite execution loop. The class ‘CheckBox‘ also uses a ‘boost::signal‘ to notify the application on changes: Again, the ‘if‘ enclosing the signal emission @NN(if_cb_1,-,if_cb_2) breaks the dependency cycle of Figure 16 to avoid infinite execution. The class ‘OptionMenu‘ creates the dependency loop by connecting the two signals: The constructor binds the signal ‘config_manager.on_mouse_grab_change‘ to the callback method ‘mousegrab_box-¿set_state‘ @NN(bind_11,-,bind_12), and also the signal ‘mousegrab_box-¿on_change‘ to the callback method ‘config_manager.set_mouse_grab‘ @NN(bind_21,-,bind_22). This way, every time the ‘ConfigManager‘ signals ‘on_mouse_grab_change‘ (‘ConfigManager‘, ln. @N(signal) [up](#cpp_config-manager)), ‘set_state‘ is implicitly called. The same happens between the signal ‘on_change‘ in the ‘CheckBox‘ and the method ‘set_mouse_grab‘ in the ‘ConfigManager‘ (‘ConfigManager‘, ln. @N(set_mouse_grab) [up](#cpp_config-manager)). Note that the signal binding to call ‘CheckBox::set_state‘ @NN(bind_false) receives a fixed value ‘false‘ as the last argument to prevent infinite execution (‘CheckBox‘, ln. @N(last_argument) [up](#cpp_check-box)). The destructor @NN(destr_1,-,destr_2) breaks the connections explicitly when the *Option* screen terminates.

In CÉU, a *Ctrl-G* key press broadcasts the internal event ‘config_manager.go_mouse_grab‘ to the application [[![X]][ceu_global_event]]: The configuration manager [[![X]][ceu_config_manager]] just needs to react to ‘go_mouse_grab‘ continuously to perform the *grab* effect: The ‘CheckBox‘ [[![X]][ceu_check_box]] exposes the event ‘go_click‘ for notifications in both directions, i.e., from the abstraction to the application and *vice versa*: The abstraction reacts to external clicks continuously @NN(every_1,-,every_2) to broadcast the event ‘go_click‘ @NN(dir_class_app). It also reacts continuously to ‘go_click‘ in another line of execution @NN(loop_1,-,loop_2), which awakes from notifications from the first line of execution or from the application. The ‘OptionMenu‘ [[![X]][ceu_option_menu]] connects the two events as follows: The two loops in parallel handle the connections in opposite directions: from the configuration manager to the check box @NN(loop_11,-,loop_12); and from the check box to the configuration manager @NN(loop_21,-,loop_22). When the *Option* screen terminates, the connections break automatically since the body is automatically aborted. Note that the implementation in CÉU does not check event emits to break the dependency cycle and prevent infinite execution. Due to the [stack-based execution for internal events][ceu_stack] in CÉU, programs with mutually-dependent events do not create infinite execution loops.

3 Related Work

4 Conclusion

We promote the *structured synchronous reactive* programming model of CÉU for the development of games. We present in-depth use cases categorized in 5 control-flow patterns applied to *Pingus* (an open-source *Lemmings* clone) that likely apply to other games.

We show how the standard way to program games with objects and callbacks in C++ hinders structured programming techniques, such as support for sequential execution, long-lasting loops, and persisting local variables. In this sense, callbacks actually disrupt structured programming, becoming [”our generations goto”][goto] according to Miguel de Icaza.

Overall, we believe that most difficulties in implementing control behavior in game logic is not inherent to this domain, but a result of accidental complexity due to the lack of structured abstractions and an appropriate concurrency model to handle event-based applications.

[goto]: http://tirania.org/blog/archive/2013/Aug-15.html

5 Acknowledgments

[Leonardo Kaplan](https://github.com/leokaplan/) and [Alexander Tkachov](https://github.com/Tkachov/) for early explorations and prototypes.

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```
class Bomber : public PinguAction {
    <...>
    Sprite sprite;
}

Bomber::Bomber (<...>) : <...> {
    sprite.load(<...>);
    <...>
}

void Bomber::update () {
    sprite.update ();
}

void Bomber::draw (SceneContext& gc) {
    <...>
    gc.color().draw(sprite, <...>);
}
```

`[a]` Implementation in C++

```
code/await Bomber (void) -> ActionName do
    <...>
    var&? Sprite sprite = spawn Sprite(<...>);
    <...>
end
```

`[b]` Implementation in CÉU

Figure 9: Shared-memory concurrency in CÉU: example `[a]` is safe because the trails access `x` atomically in different reactions; example `[b]` is unsafe because both trails access `y` in the same reaction.

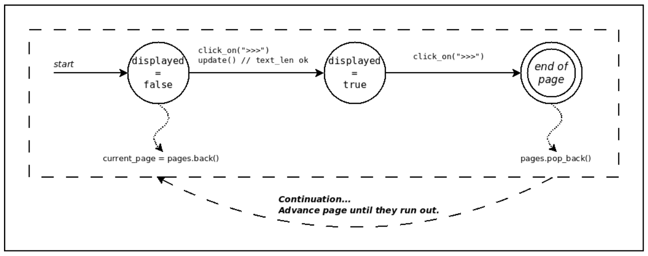

Figure 10: State machine for the Story screen.

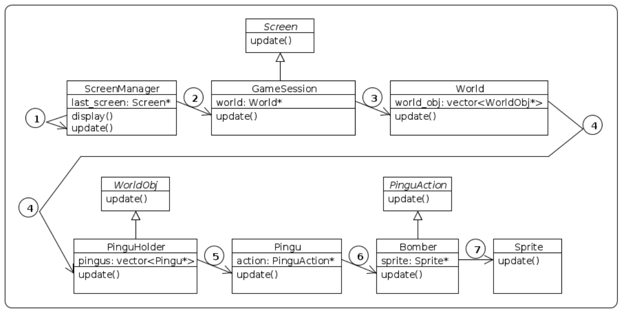

Figure 11: Dispatching chain for `update`.

```
Pingu* PinguHolder::create_pingu (<...>) {
    <...>
    Pingu* pingu = new Pingu (<...>);
    pingus.push_back(pingu);
    <...>
}

void PinguHolder::update() {
    <...>
    while(pingu != pingus.end()) {
        (*pingu)->update();
        if ((*pingu)->get_status() == Pingu::PS_DEAD)
            pingu = pingus.erase(pingu);
        }
        <...>
        ++pingu;
    }
}
```

[a] Implementation in C++

```
code/await Game (void) do
    <...>
    pool[] Pingu pingus;
    code/await Pingu_Spawn (<...>) do
        <...>
        spawn Pingu(<...>) in outer.pingus;
    end
    <...>   // code invoking Pingu_Spawn
end

TODO

code/await Pingu (<...>) do
    <...>
    loop do
        await outer.game.dt;
        if call Pingu_Rel_Getpixel(0,-1) == {Groundtype::G
            <...>
            escape {PS_DEAD};
        end
    end
end
```

[b] Implementation in CÉU

Figure 12: Shared-memory concurrency in CÉU: example [a] is safe because the trails access x atomically in different reactions; example [b] is unsafe because both trails access y in the same reaction.

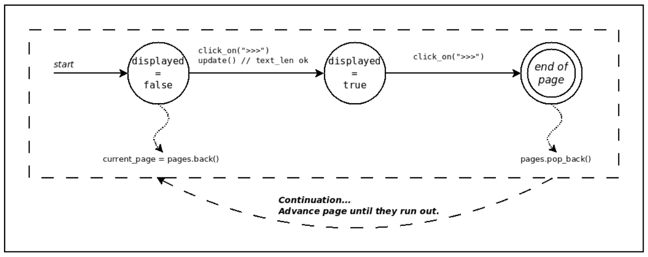

Figure 13: State machine for the Story screen.

Figure 15: The *Mouse Grab* configuration option.

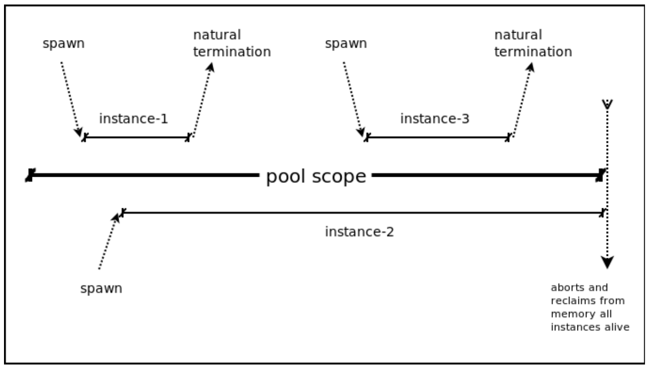

Figure 14: Lifespan of dynamic instances.

Figure 16: Mutual dependency between signals.

```
void GlobalEvent::on_button_press (<...>) {
    <...>
    switch (event.keysym.sym) {
        case SDLK_g:
            if (keystate[SDLK_LCTRL]  keystate[SDLK_R
                config_manager.set_mouse_grab(
@ctrl_g_cpp
                    !config_manager.get_mouse_grab())
            }
            break;
        <...>
    }
}

///

boost::signals2::signal<void(bool)> on_mouse_grab_cha
// definition in `config_manager.h` @signal_def

void ConfigManager::set_mouse_grab (bool v) {
@set_mouse_grab
    <...>
    if (v != get_mouse_grab()) {
@if_1
        <...>   // the actual "grab" effect
        on_mouse_grab_change(v);
@signal
    }
@if_2
}

///

boost::signals2::signal<void (bool)> on_change;
// definition in `check_box.hpp`

void CheckBox::set_state (bool is_on, bool send_signa
@last_argument
    <...>   // switches the check box state
    if (send_signal) {      @if_cb_1
        on_change(is_on);
    }                       @if_cb_2
}

///

typedef std::vector&lt;boost::signals2::connection&gt;
// definition in `option_menu.hpp`
Connections connections;
// definition in `option_menu.hpp`

OptionMenu::OptionMenu() :
    connections(),
    mousegrab_box(),
    <...>
{
    mousegrab_box = new CheckBox(<...>);
    connections.push_back(
@bind_11
        config_manager.on_mouse_grab_change.connect(
            std::bind(&CheckBox::set_state, mousegrab_
        )
    );
@bind_12
    connections.push_back(
@bind_21
        mousegrab_box->on_change.connect(
            std::bind(&ConfigManager::set_mouse_grab,
        )
    );
@bind_22
    <...>

}

OptionMenu::~OptionMenu() {     @destr_1
    for (Connections::iterator i=connections.begin();
```

```
spawn do
    var _SDL_KeyboardEvent&& e;
    every e in SDL_KEYDOWN do
        var _u8&& keystate = _SDL_GetKeyState(null);
        <...>
        if e:keysym.sym == {SDLK_g} then
            if ((keystate[{SDLK_LCTRL}] as bool) or (keysta
                emit config_manager.go_mouse_grab(
@ctrl_g_ceu
                        not ({config_manager.get_mouse_grab
            end
        end
        <...>
    end
end

///

data ConfigManager with
    event bool go_mouse_grab;
end
var ConfigManager config_manager = val ConfigManager(_);

spawn do
    var bool v;
    every v in config_manager.go_mouse_grab do
        <...>
// the actual "grab" effect
    end
end

///

data ICheckBox with
    var   bool is_on;
    event bool go_click;
end

code/await CheckBox (<...>) -> (var ICheckBox checkbox) ->
    checkbox = val ICheckBox(<...>);
    <...>
    par do
        every c.component.on_click do
@every_1
            emit checkbox.go_click(not checkbox.is_on); @di
        end
@every_2
    with
        loop do
@loop_1
            <...>
// switches the check box state
            checkbox.is_on = await checkbox.go_click;
@dir_app_class
        end
@loop_2
    end
end

///

code/await OptionMenu <...> do
    <...>
    var& CheckBox b2 = <...>;
    spawn do
        par do
            var bool v;
            every v in outer.config_manager.go_mouse_grab d
@loop_11
                emit b2.checkbox.go_click(v);
            end
@loop_12
        with
            var bool v;
            every v in b2.checkbox.go_click do
@loop_21
                emit outer.config_manager.go_mouse_grab(v);
```