

Thesis check-in - Role of aesthetics in understanding source code

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1 Introduction

After establishing ground work on aesthetic manifestations in source code for software developers during the Spring 2020 semester, I have concluded with both an empirical manifestation of beautiful code, synthesized a typology of such manifestations—how code can be beautiful—and laid out a preliminary investigation as to why code could be beautiful. Aesthetic manifestations (“beauty”) seem to occur whenever facilitate the clarity of intent of the writer, and the agency of the reader, are heightened. Beautiful code makes the underlying concepts clear and easily-graspable, and facilitates its modification by the reader by providing an error-free, and cognitively easy way to do so.

Furthermore, I outlined several directions for further research. These included the exploration of aesthetic standards for two additional categories of code writers: *source code poets* and *hackers*. Following discussions around this outcome, I have added three other directions: literary metaphors, architectural parallels and machine understanding. First, the place of literary metaphors is a response to the cognitive stake at play in reading and writing code, since code can be understood as a formal representation of mental models emerging from complex data structures and

their processing during execution time. Second, the parallels with architecture were suggested by a similar relationship to structure, planning and construction. These parallels are, as we will see below, claimed by software developers themselves, ranging from job titles to commercial best practices of software patterns; on a more theoretical level, the approaches to beauty in architecture will turn out to be productive lenses when thinking not just about executed code, but about source code as well. Third, when claiming that beautiful code facilitates understanding(s), it is important to clarify *whose* understanding of *what*. While previous work has focused on human understandings of human intentions, and human-made concepts, this document investigates to what extent do computers, as concrete machines, understand anything.

I will start by examining instances of source code poetry, defining it, contextualizing it, and analyzing it through close-readings. This will allow us to highlight specific aesthetic standards emerging from this corpus, namely *semantic layering* and *procedural rhetoric*. Source code poetry, with this clear emphasis on *poetry*, will then allow us to address the traditional relationship between literature and code, on an artistic level as well as on a linguistic one. The two concepts mentioned above will lead to an examination of the metaphor, from a literary and from a cognitive standpoint.

Particularly, the relationship that metaphors maintain to the process of knowing and understanding will be highlighted both in human texts and in program texts[1]. Connecting it to mental models will allow us to start thinking of these program texts in terms of *structure*, both surface-structure and deep-structure, and address how a theoretical framework of aesthetics might be connecting the two, including the place of imagination in acquiring knowledge and building understanding in these texts.

Mentioning structure will thus lead us into the overlap between architecture and software. After a short overview of how the two are usually related, I examine a particular set of aesthetic standards developed by Christopher

Alexander in his work on pattern languages. At the cursory level, these are tied to software patterns, techniques for developing better software that have emerged more out of practice rather than out of theory. At a deeper level, we will see that the standards of beauty—or, rather, of this *Quality Without a Name*—can be applied productively to better understand what qualities are exhibited by a program that is deemed beautiful. In particular, Richard P. Gabriel’s work will further provide a connection between software, architecture and poetry.

One particular aspect of architecture—the folly, the pavillion, and to some extent large-scale installation artworks—will allow us to transition into our next corpus: hacking. Hacking, defined further as seemingly-exclusively functional code will further requalify the need for aesthetics in source code. We will see how this practice is focused much less on human understanding than on machine understanding, on producing code that is unreadable for the former, and yet crystal-clear for the latter—with an emphasis on human and machine performance. Despite a current lack of extensive research on hacking-related program texts, we will look into two instances of these: the one-liner and the demo to support our investigation in this domain.

This brings us to the broader question of human understanding and machine understandings. Starting from the distinction between syntax and semantics, I highlight discrepancies between semantics in natural languages and semantics in programming languages to define machine understanding as an autotelic one, completely enclosed within a formal description. Coming back to Goodman, we will see how such a formal system fits as a *language of art*, and yet remains ambiguous: is computation exclusively concerned with itself, or can it be said that it relates to the rest of the (non-computable) world? Additionally, the question of aesthetics within programming languages themselves will be approached in a dual approach: as linguistic constructs presenting affordances for creating program texts which exhibit aesthetic properties, and as objects with aesthetic proper-

ties themselves. Whether or not we can agree on machine understanding, the formalism of programming languages, and their aesthetic possibilities, provide an additional perspective on the communication of non-obvious concepts inherent to computing.

In conclusion, we will see that aesthetics in code is not exclusively a literary affair in the strict sense of the term, but is rather at the intersection of literature, architecture and problem-solving, insofar as they manifest through the (re-)presentation of complex concepts and multi-faceted uses, involving their writers and readers in semantics-heavy cognitive processes and mental structures.

Finally, I suggest further directions for research.

2 Programming and literary arts

This section focuses on source code poetry, as the closest use of “literary arts” involving code. We will see how this particular way of writing software, to an explicitly aesthetic end, rather than a functional one, summons specific claims to art and beauty. These claims maintain a complex relationship to the nature and purpose of code, in certain ways embracing the former, and moving away from the latter, but nonetheless allow us to more clearly define such a nature and such purposes. After an overview of the field, including delimitation of our corpus, I will highlight and analyze particular source code poems, chosen for their meaning-making affordances, and conclude on the aesthetic standards at play in their reading and writing, expanding on notions of *double-meaning* and *double-coding*.

2.1 Overview

Source code poetry is a distinct subset of electronic literature. A broad field encompassing natural language texts taking full advantage of the dynamic feature of computing to redefine the concept of text, authorship and

readership, it nonetheless encompasses a variety of approaches, including generative literature, interactive fiction, visual poetry, source code poetry and esoteric programming languages, as well as certain aspects of software art. However, one of the distinctions that can be made in defining the elements of electronic literature which are included in our corpus is, in line with the framework of this research, the shift from output to input, for executable binary to latent source.

A large section of the works which fall within electronic literature focus on the result of an executed program, often effectively obfuscating one of the many chained acts of writing¹ which allow for the very existence of these works. For instance, the influence of *Colossal Cave Adventure*[2], the first work of interactive fiction, has been centered around on the playable output of the software, rather than on its source code. Written in FORTRAN 4 between 1975 1977, it exhibits several features which wouldn't fit within the typology we've previously established, particularly in terms of variable naming (e.g. variables such as 'KKKT', 'JSPK'; or 'GOTO' statements, whose harm has been considered at the same time this code was written²). *Colossal Cave Adventure's* source code was indeed only examined due to the recognition of the cultural influence of the game, decades later, and not for its intrinsic properties.

A more contemporary example would be that of the Twine game engine, lowering the barrier to entry for writing interactive fictions in the age of the hyperlink. The result, while aesthetically satisfying, widely recognized and appreciated by the interactive fiction community, nonetheless consists in a single HTML document, comprising well-formatted and understandable HTML and CSS markups, along with three single lines of "uglified" JavaScript³. The explicit process of uglification⁴ relies on the assumption

¹See: Béatrice Fraenkel on chains of writing

²retrieved from: <https://jerz.setonhill.edu/if/crowther/advf4.77-03-11>

³For instance, the source code of <https://pierredepaz.net/-/who/> consists of three lines of 52980 characters, and only 682 whitespace characters

⁴We could expand on this process of uglification, which consists of compacting humanly-

that no one would, or should, read the source code.

In the case of visual poetry, one can see how the source code of works such as bpNichol's *First Screening*⁵, is dictated exclusively by the desired output, with a by-product of visually pleasing artifacts throughout the code as foreshadowing the result to come⁶. It is a literal description of static, desired output, more akin to a cinematic timeline editor, in which there is a 1:1 relationship between the clips laid out and the final reel, and no room for unexpected developments. While computer-powered, such an example of visual poetry tend to side-step the *potentiality* of computing, of which source code is one of the descriptive symbol systems: each execution of the code is going to be exactly the same as the previous one, and the same as the next one⁷. While this might be a drastic example, in which unknowns are reduced to a minimum, visual poetry and interactive do rely heavily on the dynamic aspect of computer procedures to create aesthetic experiences⁸. The difference I am making here is that such aesthetic experience are claimed to take place in the realization of the computer-aided potentials of the work, rather than in the textual description of these potentials⁹. These examples, while far from being exhaustive, nonetheless show how little attention is paid to the source code of these works, since they are clearly—and rightly so—not their most important part.

Computer poetry, an artform based on the playful *détournement* of the computer's constraints, gets closer to our topic insofar as the poems generated represent a more direct application of the rule-based paradigm to laid out source code into the small possible number of characters, usually for a production-ready build, optimized for loading times and dependency processing.

⁵<https://www.vispo.com/bp/download/FirstScreeningBybpNichol.txt>

⁶Still, a lovely artefact is the subroutine at line 1600, an "offscreen romance" only visible in the source.

⁷Barring any programmer-independent variables, such as hardware and software platform differences.

⁸For instance, see Text Rain, by Camille Utterbach and Romy Achituv

⁹Tellingly, the Smithsonian Museum, which acquired Text Rain, makes no mention of the source code of the piece.

the syntactical output of the program. Starting with Christopher Strachey's love letters, generated (and signed!) by MUC, the Manchester Univac Computer, computer poems are generated by algorithmic processes, and as such rely essentially on this particular feature of programming, laying out rules in order to synthesize syntactically and semantically sound natural language poems. Here, the rules themselves matter as much as the output, a fact highlighted by their ratio: a single rule for a seemingly-infinite amount of outputs.

These works and their authors build on a longer tradition of rule-based composition, from Hebrew to the Oulipo and John Cage's indeterministic composition, amongst many others[3], a tradition in which creativity and beauty can emerge from within a strict framework of formal rules. Nonetheless, the source code to these works is rarely released in conjunction with their output, hinting again at their lesser importance in terms of their overall artistic values. If computer poetry is composed of two texts, a natural-language output and a computer-language source, only the former is actually considered to be poetry, often leaving the latter in its shadow (as well as, sometimes, its programmer, an individual sometimes different from the poet). The poem exists through the code, but isn't exclusively limited to the humanly-readable version of the code, as it only comes to life and can be fully appreciated, under the poet's terms, once interpreted or compiled. While much has been written on computer poetry, few of those commentaries focus on the soundness and the beauty of the source as an essential component of the work, and only in recent times have we seen the emergence of close-readings of the source of some of these works for their own sake¹⁰. These do constitute a body of work centered around the concept of generative aesthetics[4], in which beauty comes from the unpredictable and somewhat complex interplay of rule-based systems, and whose manifestations encompass not only written works, but games, visual and musi-

¹⁰See the publications in the field of Critical Code studies, Software studies and Platform studies.

cal works as well; still, this attention to the result make these works fall on the periphery of our current research.

The aspects of electronic literature examined so far still require computer execution in order to be fully realized as aesthetic experiences. We now turn to these works which still function as works of explicit aesthetic value primarily through the reading of their source. We will examine obfuscated code and code poetry (both at the surface level and at the deep level), to finally delimitate our corpus around the last one.

One of the earliest instances of computer source written exclusively to elicit a human emotional reaction, rather than fulfill any immediate, practical function, is perhaps the Apollo 11 Guidance Computer (AGC) code, written in 1969¹¹ in Assembly. Cultural references and jokes are peppered throughout the text as comments, asserting computer code as a means of expression beyond exclusively technical tasks¹², and independent from a single writer's preferences, since they passed multiple checks and review processes to end up in the final, submitted and executed document.

```
663 STODL CG
664      TTF/8
665 DMP* VXSC
666      GAINBRAK,1 # NUMERO MYSTERIOSO
667      ANGTERM
668      VAD
669      LAND
670 VSU      RTB
```

Code comments allow a programmer to write in their mother tongue, rather than in the computer's, enabling more syntactic and semantic flexibility, and thus reveal a burgeoning desire for programmers to express themselves within their medium of choice.

At the turn of the 1980s, following the transition to programming from an annex practice to full-fledged discipline and profession, along with the

¹¹Hamilton et. al., 1969, retrieved from <https://github.com/chrislgarry/Apollo-11>

¹²See also: "Crank that wheel", "Burn Baby Burn"

development of more expressive programming languages (e.g. Pascal in 1970, C in 1972), software development has become a larger field, growing exponentially¹³, and fostering practices, communities and development styles and patterns¹⁴. Source code becomes recognized as a text in its own, which can hold qualities and defects of its own, and to which engineering and artistic attention must be paid. No longer a transitional state from formula to binary, it becomes a semantic material, whose layout, organization and syntax are important to the eyes of its writers and readers. Pushing further into the direction of the visual layout of the code, such an endeavour becomes pursued for its own sake, equally important to the need for a program to be functional.

The Obfuscated C Code Contest¹⁵ is the most popular and oldest organized production of such code, in which programmers submit code that is functional and visually meaningful beyond the exclusive standards of well-formatted code. If the source code's meaning was previously entirely subsumed into the output in computer poetry, and if such a meaning existed in parallel in the comments of the AGC routines, pointing at the overlay of computer-related semantics (e.g. line numbers) and human-related semantics (e.g. number of the beast), obfuscated code is a first foray into closely intertwining these separate meanings in the source code itself, making completely transparent, or completely opaque what the code does just by glancing at it.

¹³Source: https://insights.stackoverflow.com/survey/2019#developer-profile-_-years-since-learning-to-code

¹⁴From Dijkstra's Notes on Structured Programming to Knuth's Literate Programming and Martin's Clean Code

¹⁵<https://ioccc.org>

traditional programming syntax¹⁷, but rather on an intuitive, human-specific understanding¹⁸.

Obfuscating practices, beyond their technical necessities (for security and efficiency), are traditionally tied to hacking practices, prominently with one-liners. As such, they rely on the brain-teasing process of deciphering, and on the pleasurable, aesthetic experience of resolving and uniting two parallel meanings: what we see in the code, and what it does¹⁹. What we focus on here is the aspect of obfuscation which plays with the different layers of meaning: meaning to the computer, meaning to the human, and different ways of representing and communicating this meaning (from uglifying, to consistent formatting, to depicting a circle with dashes and underscores). While the aesthetics at play in hacking will be further explored below, we focus on the fact that obfuscating code practices, beyond hiding the meaning and the intent of the program, also manifest an attempt to represent such a meaning in different ways, leaving aside traditional code-writing practices and suggesting the meaning of the program by challenging the abilities of human interpretation at play in the process of deciphering programs.

2.2 Source code poetry

It is this overlap of meaning which appears as a specific feature of source code poetry. In a broad sense, code poetry conflates classical poetry (as strict syntactical and phonetical form, along with poetic expressivity) with computer code, but it is primarily defined by the fact that it does not require the code to be executed, but only to be read by a human. Following the threads laid out by computer poetry and obfuscated code, code poetry starts from this essential feature of computers to work with strictly defined

¹⁷For such a program, see for instance: <https://crypto.stanford.edu/pbc/notes/pi/code.html>

¹⁸Concrete poetry also makes such a use of visual cues in traditional literary works.

¹⁹Also known informally as the “Aha!” moment, crucial in puzzle design.

formal rules, but departs from it in terms of utility. Source code poems are only functional insofar as they are accepted by the interpreter or compiler of the language in which they are written. To the computer, they are indeed functional, in that they are legal and can be parsed; but they do not do anything of *use*. Such formal compliance is only a pre-requisite, a creative constraint, for their human writers.

Within this reliance on creative constraints provided by a computing environment, the emphasis here is on the act of reading, rather than on the act of deciphering, as we've seen with obfuscated code (and in functional code in general). Source code poems are often easy to read²⁰, and have an expressive power which operates beyond the common use of programming. Starting from Flusser's approach, I consider poetry as a means to bring concepts into the thinkable, and to crystallize thoughts which are not immediately available to us[5]; through various linguistic techniques, poetry allows us to formulate new concepts and ideas, and to shift perspectives.

In their different manifestations, code poems make the boundary between computer meaning and human meaning thinner and thinner, a feature often afforded by the existence and use of higher-level programming languages. With the development of FLOWMATIC in 1955 by Grace Hopper, it was shown that an English-like syntactical system could be used to communicate concepts for the computer to process. From there, programming languages could be described along a gradient, with binary at the lowest end, and natural language (in an overwhelming majority, English) at the highest end. This implies that they could be written and read similarly to English, including word order, pronunciation and interpretation, similar to the error-tolerance of human languages, which doesn't make the whole communication process fail whenever a specific word, or a word order isn't understood.

The community of programmers writing in Perl²¹ has been one of the

²⁰See perl haikus in particular

²¹See: perlmonks, with the spiritual, devoted and communal undertones that such a name

most vibrant and productive communities when it comes to code poetry. Such a use of Perl started in 1990, when the language creator Larry Wall shared some of the poems written in the language, and it gained further exposition through the work of Shannon Hopkins[6]. The poem *Black Perl*, submitted anonymously, is a representative example of the productions of this community:

```
#!/usr/bin perl
no warnings;

BEFOREHAND: close door, each window & exit; wait until time.
    open spellbook, study, read (scan, $select, tell us);
write it, print the hex while each watches,
    reverse its, length, write, again;
kill spiders, pop them, chop, split, kill them.
    unlink arms, shift, wait & listen (listening, wait),
    sort the flock (then, warn "the goats" & kill "the sheep");
kill them, dump qualms, shift moralities,
    values aside, each one;
die sheep? die to : reverse { the => system
    ( you accept (reject, respect) ) };
next step,
    kill 'the next sacrifice', each sacrifice,
    wait, redo ritual until "all the spirits are pleased";
do { it => "as they say" }.
    do { it => (*everyone***must***participate***in***forbidden**s*e*
        x*)
    + }.
    return last victim; package body;
exit crypt (time, times & "half a time") & close it,
    select (quickly) & warn your (next victim);
AFTERWARDS: tell nobody.
    wait, wait until time;
wait until next year, next decade;
sleep, sleep, die yourself,
    die @last
```

The most obvious feature of this code poem is that it can be read by anyone, including by readers without previous programming experience: each word is valid both as English and as Perl. A second feature is the abundant use of verbs. Perl belongs to a family of programming languages grouped under the *imperative* paradigm, which matches a grammatical mood of natural languages, the *imperative mood*. Such mood emphasizes actions to be taken rather than, for instance, descriptions of situations, and thus sets a clear tone for the poem. The fact that Perl is based on stating processes implies.

dures to be executed and states to be changed creates this feeling of relentless urgency when reading through the poem, a constant need to be taking actions, for things to be changed. Here, the native constraints of the programming language interacts directly with the poetic suggestion of the work in a first way: the nature of Perl is that of giving orders, resulting in a poem which addresses *someone* to execute *something*. Still, Perl's flexibility leaves us wondering as to who and what are concerned by these orders. Is the poem directing its words to itself? To the reader? Is Perl just ever talking exclusively to the computer? This ambiguity of the addressee adds to the ominousness of each verse.

The object of each of these predicates presents a different kind of ambiguity: earlier versions of Perl function in such a way that they ignore unknown tokens²²²³. Each of the non-reserved keywords in the poem are therefore, to the Perl interpreter, potentially inexistant, allowing for a large latitude of creative freedom from the writer's part. Such a feature allows for a tension between the strict, untouchable meaning of Perl's reserved keywords, and the almost infinite combination of variable and procedure names and regular expressions. This tension nonetheless happens within a certain rhythm, resulting from the programming syntax: `kill them, dump qualms, shift moralities`, here alternating the computer's lexicon and the poet's, both distinct and nonetheless intertwined to create a *Gestalt*, a whole which is more than the sum of its parts.

A clever use of Perl's handling of undefined variables and execution order allows the writer to use keywords for their human semantics, while subverting their actual computer function. For instance, the `die` function should raise an exception, but wrapped within the `exit ()` and `close` keywords, the command is not interpreted and therefore never reaches the execution point, bypassing the abrupt interruption. The subversion here isn't purely semi-

²²e.g. undefined variables do not cause a core dump.

²³Which results in the poem having to be updated/ported, in this case by someone else than the original writer

otic, in the sense of what each individual word means, but rather in how the control flow of the program operates—technical skill is in this case required for artistic skill to be displayed.

Finally, the use of the `BEFOREHAND:` and `AFTERWARDS:` words mimic computing concepts which do not actually exist in Perl's implementation: the pre-processor and post-processor directives. Present in languages such as C, these specify code which is to be executed respectively before and after the main routine. In this poem, though, these patterns are co-opted to reminisce the reader of the prologue and epilogue sometimes present in literary texts. Again, these seem to be both valid in computer and human terms, and yet seem to come from different realms.

This instance of Perl poetry highlights a couple of concepts that are particularly present in code poetry. While it has technical knowledge of the language in common with obfuscation, it departs from obfuscated works, which operate through syntax compression, by highlighting the expressive power of semiotic ambiguity, giving new meaning to reserved keywords. Such an ambiguity is furthermore bi-directional: the computing keywords become imbued with natural language significance, bringing the lexicon of the machine into the realm of the poetic, while the human-defined variable and procedure names, and of the regular expressions, are chosen as to appear in line with the rhythm and structure of the language. Such a work highlights the co-existence of human and machine meaning inherent to any program text²⁴.

²⁴Except perhaps those which deal exclusively with scientific and mathematical concepts

```

class Proc
    def in_discomfort?; :me; end
end

you_are = you =
    ->(you) do
        self.inspect until true
        until nil
            break you
        end
        puts you.in_discomfort?
        you_are[you]
    end

you[
    you_are
]

```

The poem above, written in Ruby by maca²⁵ in 2011 and titled `self_inspect.rb`, opens up an additional perspective on the relationship between aesthetics and expressivity in source code. Immediately, the layout of the poem is reminiscent both of obfuscated works and of free-verse poetry, such as E.E. Cummings' and Stéphane Mallarmé's works²⁶. This particular layout highlights the ultimately arbitrary nature of whitespace use in source code formatting: `self_inspect.rb` breaks away from the implicit rhythm embraced in *Black Perl*, and links to the topics of the poem (introspection and *unheimlichkeit*) by abandoning what are, ultimately, social conventions, and reorganizing the layout to emphasize both keyword and topic, exemplified in the `end` keyword, pushed away at the end of their line.

The poem presents additional features which operate on another level, halfway between the surface and deep structures of the program text. First, the writer makes expressive use of the syntax of Ruby by involving data types. While *Black Perl* remained evasive about the computer semantics of the variables, such semantics take here an integral part. Two data types, the array and the symbol are used not just exclusively as syntactical necessities (since they don't immediately fulfill any essential purpose), but rather as semantic ones. The use of `:me` on line 2 is the only occurrence of

²⁵<https://github.com/maca>

²⁶Particularly *Un coup de dés jamais n'abolira le hasard*.

the first-person pronoun, standing out in a poem littered with references to `you`. Symbols, unlike variable names, stand for variable or method names. While `you` refers to a (hypothetically-)defined value²⁷, a symbol refers to a variable name, a variable name which is here undefined. Such a reference to a first-person pronoun implies at the same time its ever elusiveness. It is here expressed through this specific syntactic use of this particular data type, while the second-person is referred to through regular variable names, possibly closer to an actual definition. It is a subtlety which doesn't have an immediate equivalent in natural language, and by relying on the concept of reference, hints at an essential *différance* between `you` and `me`.

Reinforcing this theme of the elusiveness of the self, `maca` plays with the ambiguity of the value and type of `you` and `you_are`, until they are revealed to be arrays. Arrays are basic data structures consisting of sequential values, and representing `you` as such suggests the concept of the multiplicity of the self, adding another dimension to the theme of elusiveness. The discomfort of the poem's voice comes from, finally, from this lack of clear definition of who `you` is. Using `you_are` as an index to select an element of an array, subverts the role suggested by the declarative syntax of `you are`. The index, here, doesn't define anything, and yet always refers to something, because of the assignment of its value to what the lambda expression `->` returns. This further complicates the poem's attempt at defining the self, returning the reverse expression `you_are[you]`. While such an expression might have clear, even simple, semantics when read out loud from a natural language perspective, knowledge of the programming language reveals that such a way to assign value contributes significantly to the poem's expressive abilities.

A final feature exhibited by the poem is the execution of the procedure. When running the code, the result is an endless output of print statements of "me", since Ruby interprets the last statement of a program as a return

²⁷A variable name can represent a value and/or a memory address

```
...  
me  
me  
me  
me  
me  
me  
me  
me  
me  
me  
me  
me  
me  
me  
me  
  
Traceback (most recent call last):  
  11913: from poem.rb:16:in '<main>'  
  11912: from poem.rb:13:in 'block in <main>'  
  11911: from poem.rb:13:in 'block in <main>'  
  11910: from poem.rb:13:in 'block in <main>'  
  11909: from poem.rb:13:in 'block in <main>'  
  11908: from poem.rb:13:in 'block in <main>'  
  11907: from poem.rb:13:in 'block in <main>'  
  11906: from poem.rb:13:in 'block in <main>'  
    ... 11901 levels...  
      4: from poem.rb:13:in 'block in <main>'  
      3: from poem.rb:13:in 'block in <main>'  
      2: from poem.rb:12:in 'block in <main>'  
      1: from poem.rb:12:in 'puts'  
self_inspect.rb:12:in 'puts': stack level too deep (SystemStackError)
```

²⁸Both in terms of actual, and in terms of concrete poetry

The added depth of meaning from this code poem goes beyond the syntactic and semantic interplay immediately visible when reading the source, as the execution provides a result whose meaning depends on the co-existence of both source and output. Beyond keywords, variable names and data structures, it is also the procedure itself which gains expressive power: a poem initially about *you* results in a humanly infinite, but hardware-bounded, series of *me*²⁹.

2.3 Aesthetics of source code poetry

These analyses of program texts have highlighted some of the aesthetic features of source code which can elicit a poetic experience during both reading and execution. These can be further qualified through several concepts, which I introduce and extend here.

The first is **double-meaning**, taken from Camille Paloque-Bergès's work on networked texts, and her analysis of code poetics[7]. She defines it as the affordance provided by the English-like syntax of keywords reserved for programming to act as natural-language signifiers. As we've seen in *Black Perl*, the Perl functions can indeed be interpreted as regular words when the source is read as a human text. Starting from her analysis of *codeworks*, a body of literature centered around a créole language halfway between humanspeak and computerspeak³⁰, it can be extended into the aesthetically productive overlap of syntactic realms.

Previous research by Philippe Bootz has also highlighted the concept of the *double-text* in the context of computer poetry, a text which exists both in its prototypal, virtual, imagined form, under its source manifestation, and which exists as an instantiated, realized one[8]. However, he asserts that, in its virtual form, "a work has no reality", specifically because it is not realized. Here again, we encounter the dependence of the source on

²⁹Another productive comparison could be found in Stein's work, *Rose is a rose is a rose...*

³⁰See in particular the work of Alan Sondheim and mezangelle

its realized output, indeed a defining feature of the generative aesthetics of computer poetry. As we've seen in the `self_inspect.rb` poem, a work of code poetry can very much exist in its prototypal form, with its output providing only additional meaning, further qualifying the themes laid out in source beforehand. Indeed, the output of that poem would have a drastically diminished semantic richness if the source isn't also read and understood. For this double-meaning to take place, we can say that the situation is inverted: the output becomes the virtual, imagined text, while the source is the concrete instantiation of the poem.

Second, we draw on Geoff Cox and Alex McLean's concept of **double-coding**[9]. According to them, double-coding "*exemplifies the material aspects of code both on a functional and an expressive level*" (p.9). Cox and McLean's work, in a thorough exploration of source code as an expressive medium, focus on the political features of speaking through code, as a subversive praxis. They work on the broad social implications of written and spoken³¹ code, rather than exclusively on the specific features of what makes source code expressive in the first place. Double-coding nonetheless helps us identify the unique structural features of programming languages which support this expressivity. As we've briefly investigated, notably through the use of data types such as symbols and arrays in source code poetry, programming languages and their syntax hold within them a specific kind of semantics which hold, for those who are familiar with them and understand them, expressive power, once the data type is understood both in its literal sense, and in its metaphorical one. The succinct and relevant use of these linguistic features can thicken the meaning of a poem, bringing into the realm of the thinkable ways to approach metaphysical topics.

Finally, the tight coupling of the source code and the executed result brings up Ian Bogost's concept of **procedural rhetoric**[10]. Bogost

³¹Which they conflate with the practice of live-coding

presents procedures as a novel means of persuasion, along verbal and visual rhetorics. Working within the realm of videogames, he outlines that the design and execution of processes afford particular stances which, in turn, influence a specific worldview, and therefore arguing for the validity of its existence. Further work has shown that source code examination can already represent these procedures, and hence construct a potential dynamic world from the source[11]. If procedures are expressive, if they can map to particular versions of a world which the player/reader experiences³², then it can be said that their textual description can also already persuasive, and elicit both rational and emotional reactions due to their depiction of higher-order concepts (e.g. consumption, urbanism, identity, morality). As its prototypal version, source code acts as the pre-requisite for such a rhetoric, and part of its expressive power lies in the procedures it deploys (whether from value assignment, execution jumps or from its overall paradigms³³). Manifested at the surface level through code, these procedures however run deeper into the conceptual structure of the program text, and such conceptual structures can nonetheless be echoed in the lived experiences of the reader.

We've seen through this section that the poetic expressivity of source code poems rely on several aesthetic mechanisms, which can be combined for further expressive effect. From layout and syntactic obfuscation, to double-meaning through variables and procedure names, double-coding and the integration of data types and functional code into a program text and a rhetoric of procedures in their written form, all of these activate the connection between programming concepts and human concepts to bring the unthinkable within the reach of the thinkable. The next section will explore this connection further, in terms of mental models, literary metaphors and cognitive structures.

³²Versions of worlds can be explored further through Goodman's *Ways of Worldmaking*

³³e.g. declarative, imperative, functional

3 Metaphors and Mental Models

This section focuses on metaphors and mental models in both programming and literature, and how they're related to understanding and cognition, both in broad terms and in specific texts. The evokative power of the excerpts seen above make ample use of the multiple facets of understanding, switching from one frame to the other. This switch relates to the most commonly used definition of metaphor: that of labeling one thing in terms of another, thereby granting additional meaning to the subject at hand. Our approach here will bypass some of the more minute distinctions made between metonymy (in which the two things mentioned are already conceptually closely related), comparison (explicitly assessing differences and similarities between two things, often from a value-based perspective) and synecdoche (representing a whole by a subset), as they all relate to a larger, more contemporary definition of the concept.

3.1 Lakoff and Ricoeur

This part of the thesis relies especially on the works of George Lakoff and Mark Johnson, and of Paul Ricoeur, due to their requalification of the nature and role of metaphor in the 20th century. While Lakoff and Johnson's approach to the conceptual metaphor will serve a basis to explore metaphors in the broad sense across software and narrative, I also argue that Ricoeur's focus on the tension of the *statement* rather than primarily on the *word* will help us better understand some of the aesthetic manifestations of software metaphors, without being limited to tokens. Following a brief overview of their contributions, I examine the various uses of metaphor in software and in literature, touch upon the cognitive turn in literary studies, and conclude the section by the ambiguity of a cognitive account of programming.

Lakoff and Johnson's seminal work develops a theory of conceptual metaphors by highlighting their essential dependence on pre-existing cog-

nitive structures, which we associate with already-understood concepts. The metaphor maps a source domain (made up of cognitive structure(s)) to a target domain. In the process, they extend the field of applicability of metaphors from the strictly literary to the broadly cultural: metaphors work because each of us has some conception of those domains involved in the metaphorical process. Metaphors rely in part on a static understanding, resulting in a fixed meaning from the application of a given source to a given target. Some of these sources are called *schemas*, and are defined enough to not be mistaken for something else, but broad enough to allow for multiple variants of itself to be applied to various targets[12], providing both diversity and reliability. As we will see below, their approach allows us to focus not just on textual objects, but on the vast range of metaphors used specifically in computing-related environments. Given that the source of the metaphor should be grounded, with as little invariability as possible, in order to qualify a potentially ill-defined target domain, this provides us with a first foray into the inherent elusiveness and instability of computing when presented to a broader audience.

Going beyond the role of metaphors manifested in expressions such as *the desktop*, *the mouse*, or *the cloud*, we will explore Lakoff's understanding of the specifically poetic metaphor further below as preliminary work to assess the linguistic component of computing—source code. For now, to complement his broadening of the metaphorical field, we turn to Paul Ricoeur's assessment of it.

Writing in *The Rule of Metaphor*, Ricoeur operates two shifts which will help us better assess not just the inherent complexity of program texts, but the ambivalence of programming languages as well. His first shift regards the locus of the metaphor, which he saw as being limited to the single word—a semiotic element—to the whole sentence—a semantic element[13]. This operates in parallel with his attention to the *lived* feature of the metaphor, insofar it exists in a broader, vital, experienced context. Approaching the metaphor while limiting it to words is counterproductive

because words refer back to “contextually missing parts”—they are eminently overdetermined, polysemic, and belong to a wider network meaning than a single, one-to-one relationship³⁴. Looking at it from the perspective of the sentence brings this rich network of potential meanings and broadens the scope for interpretation. As we’ve briefly touched upon in the previous section when reading `self_inspect.rb`, all of the evocative meaning of the poem isn’t contained exclusively in each token, and the power of the whole is greater than the sum of its parts.

Secondly, Ricoeur inspects a defining aspect of a metaphor by the *tensions* it creates. His analysis builds from the polarities he identifies in discourse between event (time-bound) and meaning (timeless), between individual (subjective, located) and universal (applicable to all) and between sense (definite) and reference (indefinite)³⁵. The creative power of the metaphor is its ability to both create and resolve these tensions, to maintain a balance between a literal interpretation, and a metaphorical one—between the immediate and the potential, so to speak. Tying it to the need for language to be fully realized in the lived experience, he poses metaphor as a means to creatively redescribe reality. As we will be approaching the topic of syntax and semantics in programming languages, we will see that these tensions can be a fertile ground for poetic creation through aesthetic manifestations.

3.2 In literature

If the conceptual turn initiated by Lakoff and Johnson’s analysis of the metaphor broadens the horizon of their applicability beyond the strict domain of literature, it is nonetheless clear that metaphors appear and operate in particular ways in literary works, from fiction to poetry. We look at

³⁴As he sees it in the traditional, Aristotelian sense of the term.

³⁵For the extent to which source code can be considered discourse has been discussed, see: Cox and McLean, *Speaking Code*.

such specificity here in anticipation of identifying which features of poetic metaphors could be mapped to the program texts of our corpus—whether explicitly poetic, as in source code poetry, or not, as in regular source code.

So while Lakoff bases poetic metaphors on the broader metaphors of the everyday life, he also operates the distinction that, contrary to conventional metaphors which are so widely accepted that they go unnoticed, the poetic metaphor is *non-obvious*. Which is not to say that it is convoluted, but rather that it is new, unexpected, that it brings something previously not thought of into the company of broad, conventional metaphors—concepts we can all relate to because of the conceptual structures we are already carry with us, or are able to easily integrate. This echoes our mention of Flusser’s analysis of poetry as that which brings ideas into the realm of the thinkable.

It does so along four different axes, in terms of how the source domain affects the target domain that is connected to. First, a source domain can *extend* its target counterpart: it pushes it in an already expected direction, but does so even further, sometimes creating a dramatic effect by this movement from conventional to poetic. For instance, a conventional metaphor would be saying that “*Juliet is radiant*”, while a poetic one might extend the attribution of positivity associated with brightness by saying “*Juliet is the sun*”³⁶.

Poetic metaphors can also *elaborate*, by adding more dimensions to the target domain, while nonetheless being related to its original dimension. Here, dimensions are themselves categories within which the target domain usually falls (e.g. the sun has an astral dimension, and a sensual dimension). Naming oneself as *The Sun-King* brings forth the additional dimension of hierarchy, along with a specific role within that hierarchy—the sun being at the center of the then-known universe.

Metaphors gain poetic value when they *put into question* the conven-

³⁶From *Romeo and Juliet*, Act 2, Scene 2

tional approaches of reasoning about, and with, a certain target domain. Here is perhaps the most obvious manifestation of the *non-obvious* requirement, since it quite literally proposes something that is unexpected from a conventional standpoint. When Camus describes Tipasa's countryside as being *blackened from the sun*³⁷, it subverts our pre-conceptions about what the countryside is, what the sun does, and hints at a semantic depth which would go on to support a whole philosophical thought (*la pensée de midi*). Interestingly, the re-edition of *L'Étranger* for its 70th anniversary can itself be seen as a form of poetic metaphor, since it was published under Gallimard's *Futuropolis* collection. While the actual *Futuropolis* doesn't claim to focus on any sort of science-fiction publications, and rather on illustrations, the very name of the collection applies onto the work of Camus, and of the others published alongside him, can elicit in the reader a sense of a kind of avant-gardism that is still present today.

Finally, poetic metaphors *compose* multiple metaphors into one, drawing from different source domains in order to extend, elaborate, or question the original understanding of the target domain. Such a technique of superimposition creates semantic depth by layering these different approaches. It is particularly at this point that literary criticism and hermeneutics appear to be necessary to expose some of the threads pointed out by this process. As an example, the metaphor of Charles Bovary's cap, a drawn-out metaphor in Flaubert's work which ends up depicting something which clearly isn't a cap, operates by extending the literal understanding of how a cap is constructed, elaborating on the different components of a hat in such a rich and lush manner that it leads the reader to question whether we are still talking about a hat. This metaphorical composition can be interpreted as standing for the orientalist stance which Flaubert takes vis-à-vis his protagonists, or for the absurdity of material pursuit and ornament³⁸, or for the novel itself, whose structure itself is composed of complex layers,

³⁷"A certaines heures, la campagne est noire de soleil", from *Noces à Tipasa*

³⁸Which ultimately leads Emma to her demise.

under the guise of banal appearances. Composed metaphors highlight how they exist along *degrees of meanings*, from the conventional to the poetic, and further to the non-sensical. This difference of degree, rather than of kind, is one I ascribe to when it comes to delimiting corpus of the present research in different ways of writing and reading code—writing code as poetry, as tool, as a hack or as research aren't absolutely siloed off from each other.

Through these, Lakoff and Johnson highlight how metaphors *function*, and how they can be identified. Another issue they address is that of the *role* they fulfill in our everyday experiences as well as in our aesthetic experiences. Granted a propensity to structure, to adapt, to reason and to induce value judgment, metaphors are ultimately seen as a means to comprehend the world. By importing structure from the source, the metaphor in turn creates structure in our lives, in our understandings (and thus have power over us). Our understanding grasps these structures through their features and attributes (one might even call them affordances, following Gibson[14]), and integrates them as a given—in what Ricoeur would call a *dead* metaphor. This is one of their key contribution, that metaphors have a function which goes beyond an exclusive, disinterested, self-referential, artistic role. If metaphors are ornament, it is far from being a crime, because these are ornaments which, in combining imagination and truth, expand our conceptions of the world by making things *fit* in new ways.

This approach of beauty as means to understand however predates Lakoff and Johnson. Through his contribution to aesthetic philosophy, Monroe Beardsley's started touching upon metaphor from a semantic perspective. Published alongside his inquiries into the aesthetic character of an experience, and taken later on by Ricoeur as a basis for his study, *The Metaphorical Twist* implies that semantics and aesthetics might be connected through the structuring operation of the metaphor—that which elicits an aesthetic experience can do so through the creation of unexpected, or previously unattainable meaning. Ricoeur's theory of the metaphor in-

deed builds on Beardsley's conception that metaphor can have a designative role (the primary subject) which adds a "*local texture of irrelevance*", a "*foreign component*", whose semantic richness might over-reach and obfuscate the intended meaning, as well as a connotative one (the secondary subject), in which meaning is peripheral. For Ricoeur, it is indeed literary criticism, beyond logical grammar and linguistics, which hold the key to understanding metaphors. Through an analysis of Beardsley's work, he highlights the metaphor-induced tension, between central and periphery, between illuminating and obfuscating, between evidence and irrelevance.

As Beardsley inquiries into the features necessary for an aesthetic experience, of which the metaphor is part, he lists five criteria to distinguish the character of such an experience. Besides object-directedness, felt-freedom, detached-affect and wholeness, is the criteria of *active discovery*, which is

"a sense of actively exercising the constructive powers of the mind, of being challenged by a variety of potentially conflicting stimuli to try and make them cohere; exhilaration in seeing connections between percepts and meanings; a sense of intelligibility"³⁹

As such, Beardsley highlights the possibility of an aesthetic experience to make understandable, to unlock new knowledge in the beholder, and he considers metaphors as a way to do so. The stages he lists go from (1) the word exhibiting properties, to (2) those properties being made into meaning, and finally into (3) a staple of the object, consolidating into (or dying from becoming) a commonplace. This interplay of a metaphor being integrated into our everyday mental structures, of poetry bringing forth into the thinkable, and in metaphor creating a tension for such bringing-forth to happen, makes the case for at least one of the consequences of an

³⁹The Aesthetic Experience, in *The Aesthetic Point of View*[15].

aesthetic experience, and therefore one of its functions: making sense of the complex concepts of world.

More recent work in aesthetics and literary research have continued in this direction. Building on the focus on conceptual structures, the attention has shifted to the relationship between literature (as part of aesthetic work and eliciting aesthetic experiences) and cognition. This move starts from the limitation of explaining “art for art’s sake”, and inscribing it into the real, lived experiences of everyday life mentioned above, perhaps best illustrated by the question posed in Jean-Marie Schaeffer’s eponymous work—*Why fiction?*. Indeed, if literary and aesthetic criticism are to be rooted in the everyday, and in the conventional conceptual metaphors which structure our lives, our brains seem to be the lowest common denominator, and thus a good starting point for a new contribution to understanding the arts. A similar approach, related to scientific knowledge, can be seen in Michael Polanyi’s work on tacit knowledge, in which that which the scientist knows isn’t entirely and absolutely formal and abstracted, but rather embodied, implicit, experiential. This limitation of codified, rigorous language when it comes to communicating knowledge, opens up the door for an investigation of how literature and art can help with this communication, while keeping in mind the essential role of the senses and lived experience in knowledge acquisition (i.e. integration of new conceptual structures)[16].

Some of the cognitive benefits of art aren’t too dis-similar to those posed by Beardsley, but shift their rationale from strict hermeneutics and criticism to cognitive science. These benefits can be pleasure, emotion, or understanding. Terrence Cave focuses on the latter when he says that literature “allows us to think things that are difficult to think otherwise. We now examine such a possibility from two perspectives: in terms of the role of imagination, and in terms of the role of the senses.

Harris posits that literature is an object of knowledge, a creator of knowledge, and that it does so through the interplay between rational thought and imaginative thought, between the “counterfactual imagination” and our

daily lives and experiences. Through this tension, this suspension of disbelief is nonetheless accompanied by an epistemic awareness, making fiction reliant on non-fiction, and vice-versa. Working on literary allusions, Ziva Ben-Porat shows that this simultaneous activation of two texts is influenced by several factors. First, the form of the linguistic token itself has a large influence over the understanding of what it alludes to. Its aesthetic manifestation, then, can be said to modulate the conceptual structures which will be acquired by the reader. Second, the context in which the alluding token(s) appears also influences the correct interpretation of such an allusion, and thus the overall understanding of the text. This contextual approach, once again hints at the change of scale that Ricoeur points in his shift from the word to the sentence, and demands that we focus on the whole, rather than single out isolated instances of linguistic beauty. Finally, a third factor is the personal baggage (a personal encyclopedia) brought by the reader. Such a baggage consists of varying experience levels, of quality of the know-how that is to be activated during the reading process, and of the cognitive schemas that readers carry with them. Imagination in literary interpretation, builds on these various aspect, from the very concrete form and choice of the words used, to the unspoken knowledge structures held in the reader's mind, themselves depending on varied experience levels. By allowing the reader to project themselves into potential scenarios, imagination allows us to test out possibilities and crystallize the most useful ones to continue building our conception of the fictional world.

The work of imagination also relies on how the written word can elicit the recall of sensations. This takes place through the re-creation, the evocation of sensory phenomena in linguistic terms, such as the *perceptual modeling*⁴⁰ of literary works, which she defines as (linguistic) simulations relying on the senses to communicate situations, concepts, and potential realities. Depicting movement, vision, tactility and other embodied sensa-

⁴⁰Elane Scarry's expression

tions allows us to crystallize and verify the work of the imaginative process. As such, literature unleashes our imaginary by recreating sensual experiences—Lakoff even goes as far as saying that we can only imagine abstract concepts if we can represent them in space⁴¹. It seems that the imaginative process depends in part on visual and spatial projections, and suggests the fitness of the conceptual structures depicted. By describing situations which, while fictional, nonetheless are possible in a reality often very similar to the one we live in, it is easy for the reader to connect and understand the point being made by the author. So if literature is an object of knowledge, both sensual and conceptual, offering an interplay between rational and imaginative thought, it still relies on the depiction of mostly familiar situations (the protagonists physiologies, the rules of gravity, the fundamental social norms are rarely challenged). A first issue that we encounter here, in trying to connect source code and computing to this line of thought, is that code has close to no sensual existence, beyond its textual form. In trying to communicate concepts, states and processes related to code and computing, and in being unable to depict them by their own material and sensual properties, we once again resort to linguistic abstraction processes, including metaphor.

3.3 In Software

It is interesting to consider that the first metaphor in computing might be concomitant with the first instance of modern computing—the Turing *machine*. While Turing machines are widely understood as being manifested into what we call computers (laptops, tablets, smartphones, etc.), and thus definitely within the realm of machines, the Turing machine isn't strictly a

⁴¹Geoff Hinton, pioneer of modern deep-learning, has reportedly said that, to visualize 100-dimensional spaces, one should first visualize a 3-dimensional, and then "shout 100 really really loud, over and over again", source: <https://medium.com/artists-and-machine-intelligence/a-journey-through-multiple-dimensions-and-transformations-in-space-the-final-frontier-d8435d81ca51>

machine *per se*. Rather, it is more accurately defined as a mathematical model which in turn defines an abstract machine. Humans can be considered Turing machines (and, in fact, one of the implicit requirements of the Turing machine is that, given enough time and resources, a human should be able to compute anything that the Turing machine can compute), and non-humans can also be considered Turing machines⁴². Debates in computer science related to the nature of computing[17] have shown that computation is far from being easily reduced to a simple mechanical concern, and the complexity of the concept is perhaps why we ultimately revert to metaphors in order to better grasp them.

Jumping ahead to the 1980s, these uses of metaphors became more widespread and entered public discourse once personal computing became available to ever larger audiences. With the release of the XEROX Star, features of the computer which were until then described as data processing were given a new life in entering the public discourse. The Star was seminal since it introduced technological innovations such as a bitmapped display, a two-button mouse, a window-based display including icons and folders. For instance, the desktop metaphor relies on previous understanding of what a desktop is, and what it is used for in the context of physical office-work; since early personal computers were marketed for business applications (such as the Star), these metaphors built on the broad cognitive structures of the user-base in order to help them make sense of this new tool. Paul DuGay, in his cultural study of the Sony Walkman, makes a similar statement when he describes the Sony Walkman, a never-before-seen compound of technological innovations, in terms of pre-existing, and well-established technologies[18]. The icon of a floppy disk for writing data to disk, the sound of wrinkled paper for removing data from disk, the designation of a broad network of satellite, underground and undersea communications as a cloud, these are all metaphors which help us make sense

⁴²See research in biological computing, using DNA and protein to perform computational tasks

of the broad possibilities brought forth by the computing revolution.

The work of metaphors takes on an additional dimension when we introduce the concept of interfaces. As permeable membranes which enable (inter)actions between the human and the machine, they are essential insofar as they allow for various kinds of agency, based on different degrees of understanding. Departing from the physically passive posture of the reader towards an active engagement with a dynamic system, interfaces highlight even further the cognitive role of the metaphor. These depictions of things-as-other-things influence the mental model which we build of the computer system we engage in. For instance, the prevalent windows metaphor of our contemporary desktop and laptop environments obfuscates the very concrete action of the CPU (or CPUs, in the case of multi-core architecture) of executing one thing at a time, except at speeds which cannot be intuitively grasped by human perception. Alexander Galloway's work on interfaces as metaphorical representations suggests a similar concern when he bases it on Jameson's theory of cognitive mapping. While Jameson uses it in a political and historical context, the heuristic is nonetheless useful here: cognitive mapping is the process by which the individual subject situates himself within a vaster, unrepresentable totality, a process that corresponds to the workings of ideology. Substituting ideology with the computer⁴³, we can see how such a process helps make sense of the unthinkable, of that which is too complex to grasp and therefore must be put into symbols (words, icons, sounds, etc.).

Moving away from userland, in which most of these metaphors exist, we now turn to examine the kinds of metaphors that are used by programmers and computer scientists themselves. Since the sensual reality of the computer is that it is a high-frequency vibration of electricity, one of the first steps taken to productively engage with computers is that of abstraction.

⁴³The relation between which has been explored by Galloway, Chun, Holmes and others, and is particularly apparent in how an operating system is designated in French: *système d'exploitation*.

The word computer itself can be considered as an abstraction: originally used to designate the women manually inputting the algorithms in room-scale mainframes, the distinction between the machine and its operator was considered to be unnecessary. The relation between metaphor and abstraction is a complex one, but we can say that metaphorical thought requires abstraction, and that the process of abstraction ultimately implies designating one thing by the name of another (a woman by a machine's, or a machine by a woman's), being able to use it interchangeably, and therefore lowering the cognitive friction inherent to the process of specification, freeing up mental resources to focus on the problem at hand.

This need to get away from the specificities of the machines has been one of the essential drives in the development of programming languages. Since we cannot easily and intuitively deal with binary notation to represent complex concepts, programming helps us deal with this hurdle by presenting things in terms of other things. Most fundamentally, we represent binary signs in terms of English language (e.g. from binary to Assembly). This is, again, by no means a metaphorical process, but rather an encoding process, in which tokens are being separated and parsed into specific values, which are then processed by the CPU as binary signs. Still, this abstraction layer offered by programming languages allowed us to focus on *what* we want to do, rather than on *how* to do it. The metaphorical aspect comes in when the issue of interpretation arises, as the possibility to deal with more complex concepts required us to grasp them in a non-rigorous way, one which would have a one-to-one mapping between concepts. Allen Newell and Herbert A. Simon, in their 1975 Turing Award lecture, offer a good example of symbolic (i.e. conceptual) manipulation relates inherently to understanding and interpretation:

In none of [Turing and Church's] systems is there, on the surface, a concept of the symbol as something that *designates*.

The complement to what he calls the work of Turing and Church as au-

tomatic formal symbol manipulation is to be completed by this process of *interpretation*, which they define simply as the ability of a system to designate an expression and to execute it. We encounter here one of the essential qualities of programming languages: the ambivalence of the term *interpretation*. A machine interpretation is clearly different from a human interpretation: in fact, most people understand binary as the system comprised of two numbers, 0 and 1, when really it is interpreted by the computer as a system of two distinct signs (red and blue, Alex and Max, hot and cold, etc.). To assist in the process of human interpretation, I argue that metaphors have played a part in helping programmers construct useful mental representations related to computing. These metaphors can go both ways: helping humans understand computing concepts, and to a certain extent, helping computers understand human concepts.

Perhaps one of the first metaphors a programmer encounters when learning about the discipline is that which states that the function is like a kitchen recipe. You specify a series of instructions which, given some input ingredients (arguments), result in an output result (return value). The difficulty in explaining, in that context, the need for a *void* keyword to individuals with limited experience and knowledge of how programming works is a good example of the non-straightforwardness of computing concepts. Similarly, the use of the term *server* is conventionally associated and represented as a machine sending back data when asked for it, when really it is nothing but an executed script or process running on said machine. Incidentally, a server is also a style of software architecture, to which we will return later.

Another instance of symbolic use relying on metaphorical interpretation can be found in the word *stream*. Originally designating a flow of water within its bed, it has been gradually accepted as designating a continuous flow of contingent binary signs. *Memory*, in turn, stands for record, and is stripped down of its essentially partial, subjective and fantasized aspects usually highlighted in literary works (perhaps *volatile memory* gets closer

to that point). Finally, *objects*, which came to prominence with the rise of object-oriented programming, have only little to do with the physical properties of objects, with no affordance for being traded, for acting as social symbols, for gaining intrinsic value, but rather the word is used as such for highlighting its boundedness, and ability to be manipulated without interfering with other objects.

Most of these designations, stating a thing in terms of another aren't metaphors in the full-blown, poetic sense, but they do hint at the need to represent complex concepts into humanly-graspable terms. The need for these is only semantic insofar as it allows for an intended interaction with the computer to be carried out successfully—e.g. one has an intuitive understanding that interrupting a stream is an action which might result in incompleteness of the whole. This process of linguistic abstraction doesn't actually require clear definitions for the concepts involved. The example of the terminology in modern so-called cloud computing uses a variety of terms stacked up to each other in what might seem to have no clear *denotative* meaning (e.g. Google Cloud Platform offers *Virtual machine compute instances*), but nonetheless have a clear *operative* meaning (e.g. the thing on which my code runs). This further qualifies the complexity of the sense-making process in dealing with computers: we don't actually need to truly understand what is precisely meant by a particular word, as long as we use it in a way which results in the expected outcome⁴⁴.

The reverse process also brings forth issues of conceptual representation through formal symbolic means. The work of early artificial intelligence researchers consists not just in making machines perform intelligent tasks, but also implies that intelligence itself should be clearly and unambiguously represented. The work of Terry Winograd, for instance, was concerned with language processing (interpretation and generation)[19]. Through his inquiry, he touches on the different ways to represent the concept of lan-

⁴⁴See the famous comment in the UNIX source: *You are not expected to understand this*.

guage in machine-operational terms, and highlights two possible representations which would allow a computer to interact meaningfully with language. He considers a *procedural* representation of language, one which is based on algorithms and rules to follow in order generate an accurate linguistic model, and a *declarative* representation of language, which relies on data structures which are then populated in order to create valid sentences. At the beginning of his exposé, he introduces the historically successive metaphors which we have used to build an accurate mental representation of language (language as law, language as biology, language as chemistry, language as mathematics). As such, we also try to present language in other terms than itself in order to make it actionable within a computing environment.

As we've seen, metaphors are implicitly known not to be true in their most literal sense. Max Black in *Models and Metaphors* argues that metaphors are too loose to be useful in analytic philosophy, and therefore too loose for programming languages, heavily based on the analytic tradition. Yet, they still rely heavily on models in order to make human concepts graspable and operation to the computer. These tools deployed during the representational process differ from conventional or poetic metaphors insofar as they can be logically operated upon and therefore empirically verifiable or falsifiable. These models are means through which we aim at taking the conceptual structures on which metaphors also operate, and explicit them in formal symbol systems⁴⁵.

Abstraction, metaphors and symbolic representations are thus useful tools when it comes to computing, in terms of trying to represent to ourselves what it is that a computer can and effectively does, and in terms of explaining to the computer what it is we're trying to operate on (from an integer, to a non-ASCII word, to a renewable phone subscription or to human language).

⁴⁵For a further inquiry of models and theories, see Weizenbaum in *Computer Power and Human Reason*

3.4 Programming and psychology

So metaphors work in software because they do not exist just within literature, and yet remain too vague for a strict computer interpretation. Such a computer interpretation, in turn, is too complex and fine-grained for most individuals interacting with them (from end-users to most programmers and computer scientists) to be useful. The conclusion we establish here, is about how connections between mental models relate to the process of understanding, at the overlap between human understanding and computer understanding, and how aesthetic experience can affect this encounter.

The mental model offers a good starting point for exploring this overlap. A mental model, as a kind of internal symbolic representation of external reality, is a more rigorous and formal conceptual structure than a metaphor—which only offers a broad direction through evokative power, rather than an actionable basis. They are related to knowledge, since the construction of accurate and useful mental models through the process of understanding underpins knowledge acquisition. However, mental models need not be correlated with empirical truth, but extensive enough to be described by logical means. Mental models can be informed, constructed or further qualified by the use of metaphors, but they are nonetheless more precise than the cognitive structures on which metaphors rely—a mental model can be seen as a more specific instance of a conceptual structure. The term *schema*, used in cognition-influenced literary studies, again following Lakoff, is here a point of entry into the psychology of computer programming.

Francoise Détienne, in her study of how computer programmers design and understand programs[1], defines the activity of designing programs in activating schemas, mental representations that are abstract enough to encompass a wide use (web servers all share a common schema in terms of dealing with requests and responses), but nonetheless specific enough to be useful (requests and responses are qualitatively different subsets of

the broader concept of inputs and outputs). This flexibility is useful when one needs to deal with two aspects of working within a programming environment. An added complexity to the task of programming comes with the dual nature of the mental models needing to be activated: the computer's actions and responses are comprised of the prescriptive (what the computer should do) to the effective (what the computer actually does), one of the tensions at the heart of computer programming. In order to be appropriately dealt with, then, programmers must activate and refine mental models of a program which resolves this tension.

In programming, within a given context—which include goals and heuristics—, elements are being perceived, processed through existing knowledge schemas in order to extract meaning. Starting from Kintsch and Van Dijk's approach of understanding text[20], she nonetheless highlights some differences. In program texts, there is an entanglement of the plan, of the arc, of the tension, which does not happen so often in most of the traditional narrative text. A programmer can jump between lines and files in a non-linear, explorative manner. Program texts are also dynamic, procedural texts, which exhibit complex causal relations between states and events, which need to be kept track of in order to resolve the prescriptive/-effective discrepancies. Finally, the understanding of program text is first a general one, which only subsequently applies to a particular situation (a fix or an extension needing to be written), while narrative texts tend to focus on specific instances of protagonists, scenes and descriptions.

A similarity in understanding program texts and narrative texts is that the sources of information for understanding either are: the text itself, the individual experience and the broader environment in which the text is located (e.g. technical, social). Building on Chomsky's concepts, the activity of understanding in programming can be seen as understanding the *deep structure* of a text through its *surface structure*[21]. One of the heuristics deployed to achieve such a goal is looking out for what she calls *beacons*, as thematic organizers which structure the reading and understanding pro-

cess. However, one of the questions that isn't answered specifically, and which is the aim of this thesis, is to highlight how does the specific surface structure in programming result in the understanding of the deep structure.

Additional recent research in the cognitive responses to programming tasks, conducted by Ivanova et. al., do not appear to settle the question of whether programming is rather dependent on language processing brain functions, or on functions related to mathematics (which do not rely on the language part of the brain)[22]. They conclude that, while language processing might not be one of the essential ways that we process code, it also does not rely on exclusively mathematical functions. Stimulating in particular the multi-demand system, it seems that programming is a polymorphous activity involving multiple exchanges between different brain functions. What this implies, though, is that neither literature nor linguistics should be the only lens through which we look at code.

Going back to research in contemporary literary studies can start laying out threads of an answer. Jérôme Pelletier uses Carl Plantinga to define emotional responses in the face of aesthetic objects as dual: either one has an emotional response to the artefact itself (surface), or an emotional response to what it represents (deep). In the context of reading fiction, the reader is helped in their understanding by looking out for *guides* or *props*⁴⁶, which are similar to the *beacons* emphasized by D tienne. A notable difference is that the guides are suggested, implied, left as traces for the reader to subtly construct (as in the case of the cap metaphor in *Madame Bovary*), rather than explicitly stated throughout the program text (usually most obviously in the form of comments). However, we've seen previously that the use of comments is, by most programmers, not considered to be an aesthetic feature of an inspected source code, hinting at the fact that subtlety (useful subtlety), might be a desired attribute of beautiful code.

Programming is then fiction, in that the pinpointing of its source of exis-

⁴⁶Currie, 1990

tence is difficult, and in that it affords the experience of imagining contents of which one is not the source, and of which the certainty of isn't defined. Furthermore, both programming and fiction suggest surface-level guiding points helping the process of constructing mental models and conceptual representations. It is also non-fiction, in that it deals with concrete issues and problems (more often than not, a pestering bug), and that it provides a pragmatic frame for processing representations, in which assumptions stemming from burgeoning mental models can be easily verified or falsified. It might then be appropriate to treat it as such, simultaneously fiction and non-fiction.

To conclude this section, then, we can turn to Jerome Bruner, who considers that art allows us to "*reading in others' minds*", to anticipate what a writer has been intending for us to understand through their text, either program or narrative. This intent component relates to the interpretation issue mentioned above: the interpretation of the machine is different from the interpretation of the human, and therefore what also needs to be interpreted is the intent of the author. Reading is then akin to constructing a *cognitive cartography*, allowing for an experience to be made intelligible, sensible. The repeated implication of spatial and visual components of metaphors and mental models allows us to consider metaphors as an architecture of thought[23]. The next section is therefore dedicated to examining more closely the parallels between software architecture and physical architecture, and how the aesthetic standards of the latter could apply to the aesthetic standards of the former.

4 Architecture

Beyond its physical manifestation, the term architecture has also been applied to software development. While software does not deal with anything of concrete, immediate existence beyond lines of code (in contrast with hardware), it nonetheless holds similarities with physical architecture insofar as it is about the design, planning and construction of complex structures for human use, and possibly enjoyment. This section takes a closer look at this relationship, and particularly to the place of *patterns*. Patterns, as we will see, can elicit *goodness* in a construction and, through the concrete manifestation of *habitability*, itself of form of beauty.

4.1 General software architecture

Software architecture emerged as a consequence of the structured revolution[24], which was concerned more with the higher-level organization of code in order to ensure the quality of the software produced. Such an assurance was suggested by Dijkstra in two ways: by ensuring the provability of programs in a rigorously mathematic approach, and by ensuring that programs remained as readable as possible for the programmers. Structure has therefore been an essential component of the intelligibility of the software since the 1970s. It's only in the late 1990s that software architecture as a discipline has been recognized as such, stemming from a bottom-up approach of recognizing that some ways in which code is organized is better than others.

Today,

software architectural models are intended to describe the structure and behavior of a system in terms of computational entities, their interactions and its composition patterns, so to reason about systems at more abstract level, disregarding implementation details.[25]

At its most common denominator, architecture is concerned with the gross structure of a system. At its best, architecture can support the understanding of a system by addressing the same problem as cognitive mapping does: simplifying our ability to grasp large system. Jameson indeed borrows the phrase from Kevin Lynch, whose work on *The Image of the City* highlighted that our understanding of an urban environment relies on combinations of patterns (node, edge, area, limit, landmark) to which personal, imagined identities are ascribed. The process is once again that of abstraction, but goes beyond that. Garland notes that, in its most effective cases, software architecture can expose the high-level constraints on the design of a system, as well as *the rationale for making specific architectural choices*. Again, the intent of the architect (or the programmer) matters along with a purely descriptive depiction of the system. Intent (along with reuse, construction, evolution, analysis and management) is one of the crucial aspects of the computational paradigm on which the software is built.

As an example, the Linux Kernel's architecture can be considered, amongst others reasons, one of the reasons why the project became so popular once integrated into the GNU ecosystem. Along with its distribution license, two of its defining features are speed and portability. While speed can be attributed to its use of C code, also responsible to some extent for its portability, the architecture of the kernel is separated in multiple components which make its extension *relatively* simple. On one side is the monolithic architecture of the kernel, in which process and memory management, virtual file systems, input/output schedulers, device drivers and network interfaces are all lumped together in kernel space. However, this architecture also allows for dynamically loadable kernel modules, pieces of the operating system which can be added and removed to the operating system without interference with the core features. This provides a quality of extendability which further contributes to the success of the ecosystem of the Linux ecosystem (see the numerous Linux-based distributions, from Ubuntu to Red Hat and Android).

An architecture, such as that of the Linux kernel, thus provides significant *semantic* content about the kinds of properties that developers should be concerned about and the expected paths of evolution of the overall system, as well as its subparts. Other architectures include, for instance, the client-server architecture (with the peer-to-peer architecture as an alternative), the model-view-controller architecture (and its presentation-abstraction-control counterpart), and one can even find their source in chip design, with Friedrich Kittler famously claiming that the last people who ever truly wrote anything where the Intel engineers laying out the plan of the 8086 chip (which would engender the whole family of x86-based devices)[26]. In this case, this instance is one of the few which relates software architecture to its physical counterpart, albeit in a very technical sense of plans and diagrams.

In the literature consulted for this research, there are only few explicit references to beauty in software architecture design. Instead, desirable properties are those of performance, security, availability, functionality, usability, modifiability, portability, reusability, integrability and testability. Perhaps this is due to the fact that the understanding of beauty in terms of external manifestation—decoration—isn't here the main point of the endeavour. Following Adolf Loos, and inspecting software architecture diagram and specifications, it seems that in this specific case, ornament seems to be a crime: highlighting the rise of the useful object in modern civilization⁴⁷, he argues that there should be no decoration needed to contribute to the functionality of the object, for fear that it must go out of style.

Style is nonetheless present in software architecture. In this context, an architectural style typically specifies a design vocabulary, constraints on how that vocabulary is used, and semantic assumptions about that vocabulary. For example, a pipe-and-filter style might specify a vocabulary in

⁴⁷Along with its white-supremacist undertones rampant in Europe at the time

which the processing components are data transformers (filters), and the interactions are via order-preserving streams (pipes). When it comes down to programming such an architectural style, pipes and filters do have a very real existence in the lines of source code. These concepts are inscribed as the `|` character for pipes, or the `.filter()` method on the JavaScript array type, which itself has different ways of being written (e.g. with an anonymous callback function, or an externally defined function). By virtue of there being different ways being written, one can always argue for whether or not one is better than the other, ultimately resulting in better, clearer—and perhaps therefore beautiful—source code.

More specifically, the aesthetic manifestations in the form of source code enter in a dialogue with software architecture. If a good system architecture should first and foremost exhibit conceptual integrity[27], one can extend this integrity to its source code manifestation. A message-passing architecture with a series of global variables at the top of each file, or an HTTP server which also subscribes to event channels, would look ugly to most, since they betray their original concept. These concrete manifestations of a *local texture of incoherence*, to paraphrase Beardsley, might be more akin to a *code smell*, a hint that something in the program might be deeply wrong.

Different kinds of architecture all deal with structures, and these structures can only fit together in a satisfactory way if their components relate to each other in a satisfactory way. One could also make the parallel between musical orchestration, and computing orchestration as the automated configuration, coordination, deployment and maintenance of (mostly distributed) computer systems and software. If an orchestra has an architecture, it nonetheless also features virtuosos and aesthetically-pleasing phrases (dealing, once again, with tension and its resolution); if a novel has an architecture, it also has specific aesthetic manifestations in its sentences; if computer systems have an architecture, they could possibly have a beautiful manifestation in its individual components which, perhaps

not originating from its architecture, nonetheless relate closely to it.

Speaking of individual components, we can recall that before the architect came the craftsman. Architecture as a field and the architect as a role have been solidified during the Renaissance, consecrating a separation of abstract design and concrete work, in which the craftsman is relegated to the role of executioner, until the arrival of civil engineering and blueprints overwhelmingly formalized the discipline. The classical architect, here, serves as the counterpart to the computer scientist, except in an inverse relation: the architect emerged from centuries of hands-on work, while the computer scientist (formerly known as mathematician) was first to a whole field of practitioners as programmers, followed by a need to regulate and structure those practices. Different sequences of events, perhaps, but nonetheless mirroring each other. On one side, construction work without an explicit architect, under the supervision of bishops and clerks, did indeed result in significant results (e.g. Notre Dame de Paris, Basilica of Sienna). On the other side, letting go of structured and restricted modes of working characterizing computer programming up to the 1980s resulted in a comparison described in the aptly-named *The Cathedral and the Bazaar*. This essay described the Linux project, the open-source philosophy it propelled into the limelight, and how the quantity of self-motivated workers without rigid working structures (which is not to say without clear designs) can result in better work than if made by a few, select, highly-skilled individuals[28].

What we see, then, is a similar result: individuals can cooperate on a long-term basis out of intrinsic motivation, and without clear, individual ownership of the result; a parallel seen in the similar concepts of *collective craftsmanship* in the Middle-Ages and the *egoless programming* of today[29], both putting pride in the quality and beauty of their work.

The relation of craftsmanship to architecture is as important as the relationship of craftsmanship to programming. A traditional perspective on the matter is that of the motor skills, with dexterity, care and experience as es-

sential features of a craftsman's ability to realize something beautiful[30], along with self-assigned standards of quality[31]. These qualitative standards which, when pushed to their extreme, result in a craftsperson's style, are to be gained through practice and experience, rather than by explicit measurements[32]⁴⁸. Two things are concerned here: tools and materials[32]. A craftsperson should have a deep, implicit knowledge of both, what they use to manipulate (chisels, hammers, ovens, etc.) as well as what they manipulate (stone, wood, steel, etc).

This relationship to tools and materials is expected to have a relationship to *the hand*, and at first seems to exclude the keyboard-based practice of programming. But even within a world in which automated machines have replaced hand-held tools, Osborne writes:

In modern machine production judgement, experience, ingenuity, dexterity, artistry, skill are all concentrated in the programming before actual production starts.[30]

He opens here up a solution to the paradox of the hand-made and the computer-automated, as programming emerges from the latter as a new skill. If machines, more and more driven by computing systems, have replaced traditional craftsmanship's skills and dexterity, this replacement can nonetheless suggest programming as a distinctly 21st-century craftsmanship, as well as other forms of cratsmanship-based work in an information economy. Beautiful code, code well-written, is indeed an integral part of software craftsmanship[33]. More than just function for itself, code among programmers can, and should be held to beauty standards[34]. Such standards are another relationship with traditional craftsmanship—in this case, form is indeed mostly following function.

A craftsman's material consciousness is recognized by the anthropo-

⁴⁸See Pye's account of craftsmanship, and his intent to make explicit the question of quality craftsmanship and "*answer factually rather than with a series of emotive noises such as protagonists of craftsmanship have too often made instead of answering it.*"

morphic qualities ascribed by the craftsman to the material. In the case of code, adjectives such as “clean”, “elegant”, “smelly” occur over and over in online discussions of programmers. Clean code, elegant code, are indicators not just of the awareness of code as a raw material that should be worked on, but also of the necessities for code to exist in a social world. As software craftsmen assemble in loose hierarchies to construct software, the aesthetic standard is *the respect of others*[35].

Another unique feature of software craftsmanship is its blending between tools and material: code, indeed, is both. This is, for instance, represented at its extreme by languages like LISP, in which functions and data are treated in the same way[36]. In that sense, code is a material which can be almost seamlessly converted from information to information-*processing*, and vice-versa. Disregarding for now the very real impact of computing on the environment, code as a material is perhaps the only non-finite material that craftspeople can work with—along with words.

Code, then, is not just an overarching, theoretical concept which can only be reckoned with in the abstract, but also the very material foundation from which the reality of software craftsmanship evolves. An analysis of computing phenomena, from software studies to platform studies, should therefore take into account the close relationship to their material that software developers can have. As Fred Brooks put it,

The programmer, like the poet, works only slightly removed from pure thought-stuff. He builds his castles in the air, from air, creating by exertion of the imagination. Few media of creation are so flexible, so easy to polish and rework, so readily capable of realizing grand conceptual structures.[29]

This bottom-up approach to programming, of the craftsman carefully writing and assembling their code into a satisfying artefact, can be exemplified in the emergence of *patterns* in software design. Before we examine these more closely, we first turn to a the particular aspect of architectural

theory which influenced it, that of Christopher Alexander's.

4.2 Beauty in architecture

If it is still unclear whether or not beauty is part of software architecture, beauty is definitely one of the essential components, and aims, of the architect, dating back to Vitruvius's maxim that a building should exhibit *firmitas, utilitas, venustas* (solidity, usefulness, beauty). While structure is meant to, by definition, stand the test of time⁴⁹, utility can be assessed by the extent to which a building fulfills its intended function, and beauty remains elusive, more often igniting debates amongst architects, rather than creating consensus over particularly beautiful constructions⁵⁰. Different schools of beauty in architecture exist, which would could very roughly separate between *top-down* or *bottom-up* approaches.

In terms of top-down approaches, we've seen that, since beautiful software is, first and foremost, software which *runs as intended*, perhaps the first architectural standard which we can apply here is that of Louis Sullivan's *form follows function*. Due to its physical manifestation, Sullivan's statement is therefore inevitably translated into concrete, visible, and sensual consequences.

All things in nature have a shape, that is to say, a form, an outward semblance, that tells us what they are, that distinguishes them from ourselves and from each other.

[...]

It is the pervading law of all things organic and inorganic, of all things physical and metaphysical, of all things human and all things superhuman, of all true manifestations of the head, of the

⁴⁹See the still standing structures of Roman and Greek antiquities, based on a particular mixture of cement.

⁵⁰With the exception, perhaps of Frank Lloyd Wright's Fallingwater, and Ludwig Mies van der Rohe's Neue Nationalgalerie.

heart, of the soul, that the life is recognizable in its expression, that form ever follows function. This is the law.[37]

We must however keep in mind that Sullivan, within the Chicago School of Architecture, was one of the pioneers of the modern skyscraper, and therefore focused on a very particular kind of architecture, in which productivity became the only, explicit function and the context for his statement. Jacques Rancière, in his study of the Werkbund and the Bauhaus-inspired architecture, offers an alternative approach, away from the strict functionality laid out by Sullivan and by Loos before him. The simplification of forms and processes, he writes of the AEG Turbinenhalle in Berlin, which is normally associated with the reign of the machine, finds itself, on the contrary, related to art, the only thing able to spiritualize industrial work and common life[38].

Rancière offers us an additional perspective, departing from the strict function of an object or of a building, to its *use*. Such a shift moves from a structure-centric perspective (such as Le Corbusier's ideal dimensions), to a human-centric perspective (such as Lacaton & Vassal's practical extension of space and light). Peter Downton reiterates this point, when he states that *"buildings and design are often judged from artistic perspectives that bear no relation to how the building's occupants perceive or occupy the building."*[39]. The bottom-up approach is therefore one which might relate less to software architecture as a top-down, abstraction process, and more to an immediate, usable one of the craftsman as a creator who is highly conscious of the user. The work of Lynch, which we've mentioned above, stands in the tradition of various urban planners and architects such as Jane Jacobs and William H. Whyte. Whyte's work, for instance, focused on empirical observation in order to determine what makes a good space, deducing its aesthetic properties (such as flowing water, movable chairs, the presence of street food vendors, multiple-layered sitings, etc.).

Christopher Alexander also belongs to this empirical tradition of examining what makes a space *good* or not, by examining its uses and the feelings it elicits in the people who tread its grounds. First developing his theory when working on the design of the Bay Area Rapid Transit System, he elaborated an approach of architecture which does not exclusively rely on abstract design, but rather takes into account the multiple layers and factors that go into making

[...] beautiful places, places where you feel yourself, places where you feel alive[40] [...]

In this work, he focuses on how beauty is involved in moving from *disorganized complexity* to *organized complexity*, an organizing process which is not, in itself, the essence of beauty, but rather the condition for such beauty to arise. Alexander's conception of beauty, while very present throughout his work, is however not immediately concerned with the specifics of aesthetics, understood as the sensual, formal properties of an object, but rather with the existence of such objects.

In this process of achieving organized complexity, he highlights the paradoxical interplay between symmetry and asymmetry, and pinpoints beauty as the "*deep interlock and ambiguity*" of the two, a beauty he also finds in the relationship between static structures of the built environment, and the flow of living individuals in their midst. Architecture as a whole does clearly take into account the role of tension, of which it is yet another manifestation, akin to those we've seen in, amongst others, Ricoeur's analysis of the metaphor, and the resolution of the riddles presented in works of obfuscated source code.

His approach to this quality is successively named as *appropriateness*, *rightness to fit*, *not-simplicity* and *wholeness*. All of these have in common the subsequent need for a purpose, a purpose which he calls the *Quality Without a Name*. This quality, he says, is complicated to name, but nonetheless exists: it is, ultimately, the quality which sustains life, a con-

clusion which he reached after extensive empirical research: no one can name it precisely, but everyone knows what it refers to. It is the quality which makes one feel at home, which makes one feel like things make sense in a deep, unexplicable way.

Among the adjectives he uses to circle around this quality are *whole*, *comfortable*, *free*, *exact*, *egoless*, *eternal*. Since his work applies more broadly to any design-connected discipline, it also applies to software development. Using the word program as an umbrella for *code block*, we can briefly sketch out how such properties could apply to software.

A *whole* program is a program which isn't missing any features, whose encounter (or lack thereof) might cause a crash.

I see two interpretations to a program being *comfortable*. First, it is a program which does not work against its material, a piece of code which is not trying to "re-invent the wheel", when the wheel might already be built-in, or which does indeed re-invent it, if the existing wheels aren't satisfying. Second, a comfortable program is one which might be modified without fear of some unintended side-effects, without invisible dependencies which might then compromise the whole.

Free programs are programs which, anthropomorphizing set aside for an instant, lead their own lives, while being mindful of the lives of others in the shared environment (the design philosophy of the UNIX operating system of "*doing one thing well*", with its consequence of being able to compose these programs into elaborate chains of data processing, can be a good example of such freedom).

Exact programs are, then, programs which do not exhibit any verbosity, in which every line is necessary and required, without being so obscure that it hinders comfort.

A program that is too exact might be exhibiting too much of its writer's *ego*, too specific and requiring a unique kind of background knowledge

which other readers might not have⁵¹.

Finally, an *eternal* program relates to the timelessness mentioned in the title of its work—it touches upon the idea of the sublime, a deep, ambivalent feeling of something that stands beyond past, present and future. Programming might be too young of a discipline to be able to single out a precise example, but the Lisp interpreter might be a good candidate, since it is a concise, succinct way of writing an interpreter of Lisp in Lisp, embodying the essence of programming language research and some of the main principles of computation (recursion, symbols, interchangeability between data and procedures).

Alexander did conduct empirical research to find examples of such qualities, in a study led at the University of Berkley which resulted in his most popular book, *A Pattern Language*[41]. In it, he lists out 253 patterns which, he claims, form a language, akin to a Chomskian generative grammar, reusable and extendable in a very concrete way. This study has had a significant impact on the computer science community, to which we turn to next.

4.3 Patterns in software

A Pattern Language kickstarted a whole field of research based around this idea of distinct, self-contained but nevertheless composable components. In Alexandrian terms, they are a triad, *which expresses a relation between a certain context, a problem, and a solution..* Similarly to architectural patterns, these emerged in a bottom-up fashion: individual software developers found that particular ways of writing and organizing code were in fact extensible and reusable solutions to common problems which could be formalized and shared with others.

Besides the theoretical similarities between software and architecture mentioned above, it is the lack of learning from practical successes and fail-

⁵¹See *egoless programming*, mentioned above.

ures in the field which prompted interest in Alexander's work, along with the development of Object-Oriented Programming, first through the Smalltalk language, then with C++, ⁵². The similarity between a pattern and an object, and their promise of using them which would lead to better results on multiple dimensions, made it very attractive to software developers. Writing in *Patterns of Software* (with a foreword by Alexander), Richard P. Gabriel illustrates that point:

The promise of object-oriented programming—and of programming languages themselves—has yet to be fulfilled. That promise is to make plain to computers and to other programmers the communication of the computational intentions of a programmer or a team of programmers, throughout the long and change-plagued life of the program. The failure of programming languages to do this is the result of a variety of failures of some of us as researchers and the rest of us as practitioners to take seriously the needs of people in programming rather than the needs of the computer and the compiler writer.[42]

The real issue raised here in programming seems to be, again, not to speak to the machine, but to speak to other humans. This complexity of communication, had always asked to be solved, perhaps at this point in the form of object-orientation. Understanding software is hard. Creating, identifying, and formalizing patterns into re-usable solutions turns out to be at least as hard[43]. Part of this comes from a lack of visibility of code bases (most of them being closed source), but also from the series of various economic and time-sensitive constraints to which developers are subject to (and echoes those in the field of architecture), and which result in moving from making something great to making something good enough to ship. The promise of software patterns seemed to offer a way out by—laboriously—codifying know-how.

⁵²today most of the programming languages allow for some object-oriented paradigm

Throughout his work, Gabriel weaves parallels between his experience as a software developer and as a poetry writer, drawing concepts from the latter field into the former, and inspecting it through the lens of pattern languages. Two concepts in particular are worth examining a bit further: *compression* and *habitability*.

Compression, in narrative and poetic text, is the process through which a word is given additional meaning through the rest of the sentence. In a sentence such as "*Last night I dreamt I went to Manderley again.*"⁵³, the reader is unlikely to be familiar with the exact meaning of *Manderley*, since this is the first sentence of the novel. However, we can infer some of the properties of Manderley from the rest of the sentence: it is most likely a place, and it most likely had something to do with the narrator's past, since it is being returned to. A similar phenomenon happens in source code, in which the meaning of a particular expression or statement can be derived from itself, or from a larger context. In object-oriented programming, the process of inheritance across classes allows for the meaning of a particular subclass to be mostly defined in terms of the fields and methods of its subclasses—its meaning is compressed by relying on a semantic environment, which might or not be immediately visible. This, Gabriel says, induces a tension between extendability (to create a new subclass, one must only extend the parent, and only add the differentiating aspects) and context-awareness (one has to keep in mind the whole chain of properties in order to know exactly what the definition of an interface that is being extended really is). Resolving such a tension, by including enough information to hint at the context, while not over-reaching into verbosity, is a thin line of being self-explanatory without being verbose.

This recalls the idea of *semantic proximity*, extracted from our analysis of programmers' comments and opinions on what they found makes code beautiful. Such a pattern does however contrast with the nature of

⁵³From Daphne DuMaurier, *Rebecca*.

object-oriented programming, in which inheritance (and subsequent local abstraction of subclasses) is considered best practice. Gabriel calls this idea *locality*: it is

that characteristic of source code that enables a programmer to understand that source by looking at only a small portion of it.[42]⁵⁴

Finally, Gabriel, writing in 1998, mentions that compression isn't so much a problem in poetry since, ultimately, the definitions of each words aren't quite limited to the poet's own mind but, as we've seen, also existing in the broad conceptual structures which readers hold. However, since all aspects of a program is always by definition explicitly defined, programmers thus have the ultimate say on the definition of most of the data and functions described in code. Compression doesn't work as well because the reader cannot assume anything that is being mentioned in the code (and defined elsewhere), without risking the (error-raising) consequence of being wrong.

His particular assumption that others will want to modify and extend source code is one that is influenced by his background as a commercial developer. Other pieces of code might just be satisfying in being read or deciphered (as we've seen in source code poetry) but this assumption of interaction with the code brings in another concept, that of *habitability*. In his terms, it is

the characteristic of source code that enables programmers, coders, bug-fixers, and people coming to the code later in its life to understand its construction and intentions and to change it comfortably and confidently.[42]

⁵⁴He adds that this isn't so much an issue if one is using a powerful and efficient IDE—which opens up the question of the role of tools and technical mediators in the reading and writing process...

In a sense, then, beautiful code is also code that is clear enough to inform action and, well-organized enough to warrant actually taking that action⁵⁵. It relates to Alexander's property of *comfort*, by affording involvement instead of estrangement. A specific instance of habitability, in software patterns, might be difficult to pinpoint, but can pop up in some cases: a beautiful commit is a commit which adds a significant feature, and yet only change the lines of the code that are within well-defined boundaries (e.g. a single function), leaving the rest of the codebase untouched, and yet affecting it in a fundamental way.

Still, such a feature of habitability, of supporting life, doesn't specify at all what it could, or should, look like. Rather, we get from Alexander a negative definition:

The details of a building cannot be made alive when they are made from modular parts.... And for the same reason, the details of a building cannot be made alive when they are drawn at a drawing board.[40]

If modularity itself is at odds with making good (software) constructions, then its implementation under the terms of an object-oriented programming paradigm becomes complicated.

Indeed, the technical formalization of the field came with the release of the *Design Patterns: Elements of Reusable Object-Oriented Software* book, which lists 23 design patterns implementable in software[44]. Its influence (in terms of copies sold, and in terms of papers, conferences and working groups created in its wake) is undeniable, with Alexander himself giving a keynote address at the ACM two years after the release. It has, however, been met with some criticism.

Some of this criticism is that patterns are "external", they look like they come from somewhere else, and are not adapted to the code. In this sense,

⁵⁵Recall the developer who mentioned that beautiful code he saw was code which clearly separated hardware dependent sections from hardware independent sections.

they join Alexander in being wary of constructions which do not integrate fully within their environments, which do not, in an organic sense, allow for a *piecemeal growth*⁵⁶. If patterns express relations between contexts, problems and solutions, then it seems that one of the main complaints of developers looking at their code and seeing chunks of foreign code dumped in the middle to fix some generic problem⁵⁷, is the lack of understanding of *context* offered by those proposed solutions. In this, blindly applying patterns from a textbook might be a solution, but it's not an elegant one.

The other criticism is that software patterns are often workarounds for features that a particular programming language doesn't allow from the get-go, or offer more convoluted implementations when written in Smalltalk and C++ than, for instance, Lisp⁵⁸. One aspect that has been eluded so far, and perhaps the most inescapable context of all, is the programming language used. One doesn't write Ruby like one writes Java(tm), or C++, and certainly not Lisp.

To conclude this section, we've seen that architecture can offer us some heuristics when looking for aesthetic features which code can exhibit. Starting from the naïve understanding that *form should follow function*, we've examined how Alexander's theory of patterns, and its significant influence on the programming community⁵⁹, points not just to an explicit

⁵⁶Addressing this concern, the failure of strict top-down hierarchies in software development resulted in the agile methodology for business teams

⁵⁷The example of the best pattern to retro-fit an air conditioner on a building would be a non-problem if the air-conditioning had been designed in from the get-go <https://wiki.c2.com/?PatternsAreNotTheLesserOfTwoEvils>.

⁵⁸Peter Norvig highlights that most patterns in the original book have much simpler implementations in Lisp, see: [urlhttp://www.norvig.com/design-patterns/design-patterns.pdf](http://www.norvig.com/design-patterns/design-patterns.pdf)

⁵⁹even spawning short-lived debates about his quality without a name on stackoverflow: <https://stackoverflow.com/questions/458242/quality-without-a-name-qwan-examples>.

conditioning of form to its function (in which case we would all write hand-made Assembly code), but rather to an elusive, yet present quality, which is both problem- and context-dependent. It is a quality that is aware of the context that the writer and reader bring with them, and of the context that it provides them, making it *habitable*. Software architecture and patterns aren't, however, explicitly praised for their beauty, perhaps because they disregard these contexts—by definition, they're high-level abstractions. Generic solutions are rarely elegant solutions. Circling back to our investigation of software as craftsmanship, we now turn to examine more closely both the tools and the material of programmers: programming languages.

5 Programming languages

Programming languages have so far been set aside when examining which sensual aspects of source code resulted in what could be deemed a “beautiful” program text. Since we’re focusing on semantics (deep-structure) represented through syntax (surface-structure), and since programming languages are in essence the frame for defining legal syntax, this section examines the influence of programming languages in the aesthetic features of source code. To do, we first go over a broad description of programming languages, concluding on what makes a programming language expressive. Second, we relate their formal aspect to Goodman’s *Languages of Art*, and assess whether or not they are a good fit as an artistic, expressive system. Third, we touch upon the problem of semantics in programming languages, and how they might differ from a human understanding of semantics. Finally, we highlight a couple of computing-specific concepts which are made explicit by programming language research, and further define the kinds of concepts that are defined and manipulated when writing code.

All in all, this will allow us to highlight how programming languages engage with the problem of aesthetics and understanding from a systemic point of view, and how they act as an interface between human and machine understanding.

5.1 Theoretical programming languages

A programming language is a strictly-defined set of syntactic rules and symbols for describing instructions to be executed by the processor. The history of programming languages is, amongst others, the history of decoupling the means of creating software from hardware. The earliest programming languages were embedded in hardware itself, such as piano rolls and punched cards for Jacquard looms. Similarly, the first electric comput-

ers then required manual re-wiring of the mainframes in order to implement any change in the algorithm being computed, which then gave way to the stack of cards fed into the machine (similar to those used to programmed the Apollo landing unit whose source code we've seen above). It is with the shift to the stored-program model, at the dawn of the 1950s, that the programs could be written, stored, recalled and executed in their electro(-mecha)nical form, essentially freeing the software result from any immediately material representation.

This engineering tendency to separate software from hardware saw a parallel in the development of programming languages themselves. Based on Turing's design, any instruction processed by the machine, needs to, ultimately, execute one of the built-in (literally, hardwired) instructions of the processor. Also called *machine language*, these instructions set describe the specific implementation of the most common operations executed by a computer (e.g. `add`, `move`, `read`, `load`, etc.). While these are represented as binary numbers to the processing unit (as is everything else), some of the first programming languages did not require the writer to write those numbers themselves. Instead, they could use a family of languages called Assembly, which are instructions whose syntax is loosely based on English and translates in turn to machine instructions. Considered today as some of the most low-level code one can write, Assembly languages were machine-dependent, featuring a one-to-one translation from English keywords to the kind of instruction sets they were programmed to generate. As such, a program written on a particular model of a computer could not be executed without any modifications on a another machine.

The first widely acknowledged high-level language which allowed for a complete decoupling of hardware and software was FORTRAN⁶⁰. At this point, programmers did not need to care about the specifics of the machine that they were running on anymore. Moving away from "hand-crafted" As-

⁶⁰With Plankalkül, Short Code and Autocode as partial proposals before it.

sembly code, FORTRAN, and the subsequent COBOL, Lisp and ALGOL 58 also started being concerned with the specific definition of their syntax in a non-ambiguous manner. Using BNF notation, it became possible to formalize their syntactic rules in order to prevent any unexpected behaviour and support rigorous reasoning for the implementation and research of current and subsequent languages. With such specifications, and with the decoupling from hardware, programming languages became, on paper, *context-free*.

The context-free grammatical basis for programming allowed for the further development of compilers and interpreters. These two are themselves binary programs which, given an syntactically-valid program text, output their machine code representation, a representation which can then be executed by the CPU⁶¹. A defining aspect of programming languages henceforth is their theoretical *lack of ambiguity*, both in their roots in formal mathematic notation (for instance, Plankalkül was based on Frege's *Begriffsschrift*) and their physical representation (punch cards are essentially discrete—hole or no hole).

Nowadays, most programming languages are Turing-complete: their syntax can implement a Turing machine and therefore simulate any possible computational aspects of any physical computer. This means that any programming language that is Turing-complete is equivalent to any other Turing-complete programming language, creating essentially a chain of equivalency between all programming languages. And yet, programming language history is full of rise and fall of languages, of hypes and disappointments, of self-claimed beautiful ones and criticized ugly ones. This is because, given such a wide, quasi-universal problem set, there are different approaches to doing so, echoing what Gilles Gaston-Granger calls *style*, as a formal way to approach the production and communication of

⁶¹The main difference between a compiler and an interpreter is that the compiler parses the whole program text as once, resulting in a binary object, while interpreters parse only one line at a time, which is then immediately executed

aesthetic, linguistic and scientific works[45]. We've already seen one difference in approaching the domain of computation: compilation vs. interpretation. Another high-level category we turn to now is that of programming paradigms.

A programming paradigm is an approach to programming based on a coherent set of principles, sometimes involving mathematical theory. Some of these concepts include hierarchy (in OOP), symbol manipulation (in functional languages), events (such as in Java) or concurrency (in Go). Each paradigm supports a set of concepts that makes it the best for a certain kind of problem[46]. These concepts in turn act as stances which influence how to approach, represent and prioritize all basic components that are involved in a programming language:

- **data** (what kinds of basic datatypes are built-in the language, e.g. signed integers, classes)
- **primitive operations** (how can the programmer directly operate on data, e.g. boolean logic, assignments, arithmetic operations)
- **sequence control** (how the flow of the program can be manipulated and constrained, e.g. if, while statements)
- **data control** (how the data can be initialized and assigned, e.g. type-safe vs. type-unsafe)
- **storage management** (how the programming language handles input/output pipelines)
- **operating environment** (how the program can run, e.g. virtual machine or not)

Every programming language of practical use takes a particular approach to those basic components, sometimes backed by an extended rationale (e.g. ALGOL 68), or not (e.g. JavaScript). In the case in which we

are circumscribed to context-free grammars, it would be possible to optimize a particular language for an objective standard (e.g. compile time, time use, cycles used). Still, computers exist to solve problems, those problems are diverse in nature and therefore necessitate different approaches (as we've seen in our discussion of the limitations of patterns above⁶²). These different approaches to what is referred to as the *problem domain* in turn influenced the development of those different paradigms, since a problem domain might have different data representations (e.g. objects, text strings, formal rules, dynamic models, etc.). Two of the early programming languages, FORTRAN and Lisp, addressed to very different problem domains: the accounting needs of businesses and the development of formal rules for artificial intelligence, respectively. Some of the overarching programming paradigms are imperative (FORTRAN), functional (Lisp), object-oriented (Smalltalk) or logic (Prolog). Without diving deeper in some of the worldmaking assumptions of each of these paradigms, they are here sufficient proof to show that, while there is only one Turing-completeness, there are widely different approaches to it, some being better than others when given a specific problem.

What makes a good programming language is a matter which has been discussed amongst computer scientists, at least since the `goto` statement has been publicly considered harmful. Some of these discussions include both subjective arguments over preferred languages, as well as objective arguments related to performance and ease-of-use. According to Pratt and Zelkowitz:

The difference among programming languages are not quantitative differences in what can be done, by only qualitative differences in how elegantly, easily and effectively things can be done.[47]

Without then jumping immediately to aesthetic details of the languages

⁶²See awk as a kind of fundamentally pattern-based scripting language.

they write in, programmers still express preferences (if not outright allegiances, sometimes calling themselves Pythonistas, or Rubyists). One must also keep in mind that there is a difference between considering a programming language good or beautiful *in itself*, and considering the programs written in the programming language. Turing-completeness offers an interesting challenge to the Sapir-Whorf hypothesis—if natural languages might only weakly affect the kinds of cognitive structures speakers of those languages can construct, programming languages are claimed to do so to large extents⁶³, even though they can all do the same thing in theory—only *how* they do it matters. These differences in the ways of doing illustrates how, in reality, different programming languages are applicable to different domains, and do so through different kinds of notations—different aesthetic features when it comes to realizing the same task.

Of the two programs presented below, the output result is exactly the same, but the aesthetic differences are obvious.

⁶³See Alan Perlis's Epigrams on Programming: "A language that doesn't affect the way you think about programming, is not worth knowing.", <https://web.archive.org/web/19990117034445/http://www-pu.informatik.uni-tuebingen.de/users/klaeren/epigrams.html>

```

package main
import "fmt"

func main() {
    var greeting = "Hey, there."
    fmt.Println(greeting)
}

```

The code above is written in Go, a language designed by Pike, Thompson and Griesemer in 2009, while the code below is written in Java, designed by James Gosling in 1995. Both are statically typed, compiled languages that are heavily influenced by C/C++ syntax, but Go is significantly younger than Java (relatively to programming languages' short history)

```

import java.io.*;

public class Greeting
{
    public static void main(String[] args)
    {
        String greeting = "Hey, there";
        System.out.println(greeting);
    }
}

```

These two snippets might seem very similar at first glance⁶⁴ From these two snippets, we can explore some of the most important criteria in programming language design: *abstraction*, *simplicity* and *orthogonality*[48], and how they underpin the writing of good programs.

Abstraction is the ability of the language to allow for the essential idea of a statement to be expressed without being encumbered by specifics which do not relate directly to the matter at hand, or to no matter at all. Abstract programming languages can lead to more succinct code, and tend

⁶⁴For a radically different approach, see: `greeting = "Hey there"; print greeting`, a valid program in Ruby, Python and Perl, all scripting languages.

to hide complexity (of the machine, and of the language), from the programmer. For instance, the Java snippet above explicitly states the usage of the `System` object, in order to access its `out` attribute, and then call its `println()` method. While a lot of code here might seem verbose, or superfluous, it is in part due to it being based on an object-oriented paradigm. However, `out` object itself might seem to go particularly contrary to the requirement of programming languages to abstract out unnecessary details: `println()` is definitely a system call dealing with I/O, and therefore already implicitly relates to the output; one shouldn't have to specify it explicitly. In contrast, Go abstracts away the system component of the print call inside the import statement `import "fmt"`. Printing, in Java, does not abstract the machine, while printing, in Go, abstracts it away in order to focus on the actual appearance of the message ("`fmt`" stands for "format"). Another abstraction is that of the language name itself from the import statements. When we write in Java, we (hopefully) know that we write in Java, and therefore probably assume that the default imports come from the Java ecosystem—there shouldn't be any need to explicitly redeclare it. For instance, `System.out.println()` isn't written `java.io.System.out.println()`. In contrast, the Go snippet hides the implicit `import "go/fmt"`, allow the programmer to focus, through visual clarity, on the real problem at hand, which is the logic of the program. In this direction, languages which provide more abstraction (such as Python), or which handle errors in an abstract way (such as Perl) tend to have greater readability by focusing on the most important tokens, rather than aggregating visual clutter—also called verbosity.

Related to abstraction, and a topic in itself, is the criteria of *typing*, the process of specifying the type of a variable or of a return value (such as integer, string, etc.). A strictly-typed language such as C++ might end up being unreadable because of its verbosity, while a type-free language might be simple to read and write (at a small-scale), but dangerous to run in production. The tradeoff here is again between being explicit and safe (because a word cannot usually and intuitively be operated on in a similar way

as a floating-point number), and being implicit, subtle, and dangerous (such as JavaScript's very liberal understanding of typing). With experience, typing can usually be inferred by purely aesthetic means: Python's boolean values are capitalized (`True`, `False`) and its difference between string and byte is represented by the use of double-quotes for the former and single-quotes for the latter. In the case above, explicitly having to mention that `greeting` is of type `string` is again redundant, since it is already hinted at by the double-quotes (and, indeed, single quotes are byte types in Java as well). Go doesn't force programmers to explicitly declare variable types (they can, if they want to), but in this case they let the computers do the heavy lifting of specifying something that is already obvious to the programmer.

A particularly note-worthy example of an elegant solution to the tradeoff between type safety and readability can be found in Go's handling of error values returned by functions:

```
d, _ := exec.LookPath("date")
fmt.Println("Today is %s", d)
```

The `_` character which we see on the first line is the choice made by Go's designers to force the user to both acknowledge and ignore the potential error value that is returned by executing the external command. This particular character, acting as an empty line, *represents absence*, not cluttering the layout of the source, while reminding subtly of the *potential* of this particular statement to go wrong and crash the program. Abstraction is therefore a tradeoff between explicitly highlighting the computer concern (how to operate practically on some data or statement), and hiding anything but the human concern (whether or not that operation is of immediate concern to the problem at hand at all). As such, languages who offer powerful abstractions tend not to stand in the way of the thinking process of the programmer. This particular example of the way in which Go deals with error-handling is a great example of the designer's explicit stylistic choice. In the words of Niklaus Wirth:

Stylistic arguments may appear to many as irrelevant in a technical environment, because they seem to be merely a matter of taste. I oppose this view, and on the contrary claim that stylistic elements are the most visible parts of a language. They mirror the mind and spirit of the designer very directly, and they are reflected in every program written.[49]

Orthogonality, in turn, relates to the ability of a small set of simple syntactic constructs to be recombined in order to achieve greater complexity, while remaining independent from each other. A direct consequence of such a feature is the ease with which the programmer can familiarize themselves with the number of constructs in the language, and therefore their ease in using them without resorting to the language's reference. Relating back to Ricoeur, the orthogonality of a language offers a simple but

powerful solution to the polysemy of the word (here, token) as embedded within a broader sentence (here, statement). The expressivity of a statement comes not just from the individual keywords, but rather from their combination. For instance, the example of Lisp treats both data and functions in a similar way, essentially allowing the same construct to be recombined in powerful ways (again, the Lisp interpreter comes to mind), while the Ruby language, and its foundational design choice which makes every type (themselves abstracted away) a class allows for greater creativity, through familiarity, in writing code, making the language itself more habitable. Orthogonality also implies independence, since all constructs operate distinctly from each other, while remaining related, because in cooperation with each other. This offers a solution to the cognitive burden of the *non-atomicity* of computer programs, in which data can end up being tangled in a non-linear program execution, and become unreadable. This unreadability is triggered, not by verbosity, but because of the uncertainty of, and confusion about, the potential side-effects caused by any statement. Such independence in all constructs in turn presents a kind *symmetry*, itself is a well-accepted aesthetic feature of any artefact, in that the use of each of the constructs is similar. This similarity eases the cognitive friction in writing and reading code since an orthogonal language allows the programmer to rely on the fact that, deep down, everything is the same, and not a collection of quirks and arbitrary decisions. For example, the below C code is illegal:

```
int[] getListOfPrimeNumbers(){
    //-- this function is illegal!
}
```

The above code is a specific instance of one of those quirks: the fact that C cannot return arrays from functions requires both a deep knowledge of the language implementation and a willingness to accept that this is how things are, even though other languages allow for such a feature. In

this case, the language exhibits an un-orthogonal property since the two constructs (`return` and `int[]`) interact with each other in non-independent ways.

Finally, one of the consequences of such a feature is the shift from computer semantic interpretation (usually connected to strongly-typed languages) to human-interpretation (and weakly-typed languages). Non-orthogonality implies that the compiler (as a procedural representation of the language) has the final say in what can be expressed, while orthogonal languages leave more leeway to the writer in keeping track of which value and statement does what, allowing for both more creativity and more uncertainty in the interpretation and execution of the program.

Both of these features, abstraction and orthogonality, ultimately relate to simplicity:

Simplicity enters in four guises: uniformity (rules are few and simple), generality (a small number of general functions provide as special cases a host of more specialized functions, orthogonality), familiarity (familiar symbols and usages are adopted whenever possible), and brevity (economy of expression is sought).[50]

The point of a simple programming language is a programming language which does not stand in the way of the program being written, or of the problem being addressed. If one is to write a program related to an interactive fiction in which sentences are being input and output in C, then the apparently simple data structure `char` of the language reveals itself to be cumbersome and complex when each word and the sentence that the programmer wants to deal with must be present not as words, but as series of `char` (hence the origin of the name of the data type `string`, as a continuous series of `char`). As we've seen, a simple language does not mean that it is easy (perhaps the simplest language of all being lambda-calculus, is far from an easy construct to grasp), but that it is just a means to an end, akin

to any other tool or instrument⁶⁵.

Programming languages, however, are *symbolic* tools, manipulating *symbolic* matter. As a formal system of symbols which can sustain creations with aesthetic features, programming languages do share commonalities with Goodman's *Languages of Art*.

Goodman develops in his opus a systematic approach to symbols in art, freed from any media-specificity (from pictorial symbols to musical notations and even time marks on clocks and watches). With it, he accomplished two things: he highlights the ways in which symbols systems have expressive and communicative power (through the dyads of denotation and exemplification, description and representation, possession and expression), and what are the kinds of requirement that such a system must have in order to develop these expressive and communicative abilities. These requirements are that of unambiguity, syntactic and semantic disjointness, and differentiation. Looking at programming languages from this perspective argues for their communicative and expressive power. From the perspective of the computer, programming languages are unambiguous insofar as any expression or statement will ultimately result in an unambiguous result by the CPU (if any ambiguity remains, the program crashes). They are also syntactically and semantically disjointed (i.e. clearly distinguishable from one another). The use of formal notations, such as BNF, had for aim to resolve any possible ambiguity in the syntax of the language in a very clear fashion. The semantics of programming languages, as we will see below, also aim at being thoroughly disjointed: a variable cannot be of multiple types at the same time. Finally, programming languages are also differentiated systems since no symbol can refer to two things at the same time.

The tension arises when it comes to the criteria of unambiguity, from a human perspective. The most natural-language-like component of pro-

⁶⁵For a further parallel on musical instruments, see Rich Hickey's keynote address at RailsConf 2012: <https://www.youtube.com/watch?v=rI8tNMsozo0>

grams, the variable and function names, always have the potential of being ambiguous (e.g. does `int numberOfFlowers` refer to the current number of flowers in memory? To the total number of potential of flowers? To a specific kind of number whose denomination is that of a flower?). We consider this ambiguity a productive opportunity for creativity, and a hindrance for program effectiveness. So, given the qualification of programming languages as symbolic systems, we could expand our short analysis above by inspecting how programming languages allow for program texts which denote, label, represent, etc. in order to further argument how source code has the potential, and has examples, of being an artistic mean of expression and comprehension, from a cognitive point of view.

If they are aesthetic symbol systems, then they can also elicit emotional responses. As we've seen with software patterns, what also matters to programming languages is not just their design, but their *situated* use:

Before closing, let me mention another essential ingredient, one that hardly ever gets mentioned: It must be a pleasure and a joy to work with a language, at least for the orderly mind. The language is the primary, daily tool. If the programmer cannot love his tool, he cannot love his work, and he cannot identify himself with it.[49]

In the next section, we turn the everyday use of programming languages, with a highlight on two aspects: *idiomatic expressions* and *esoteric languages*.

-
- syntactic sugar, idioms and how it can resolve the tension between the specific and the universal by being a friend to the programmers

(ruby is simple cause orthogonal, abstract, and fun to play with (problem: slow))

- Esoteric languages
- Show how it matches Goodman's definition in *Languages of Art* (density, disjointedness, boundedness).

5.2 Programming Semantics

The reasoning behind such a formal approach to programming languages, besides the very material machine requirements of a circuit design based on discrete distinctions, is, according to the designers of ALGOL 58, the dissatisfaction with the fact that subtle semantic questions remained unanswered remained unanswered due to a lack of clear description[51].

This section aims at answering the question: under what form do semantics exist, and to what extent can we say that computers understand?

- Approach it first in a very practical way (parse trees, tokens, environments), and then in a more theoretical way (what are the meanings that we are trying to communicate?)
- Programming semantics do exist according to the textbooks, but in the end they're just another *décalage*, describing semantics as a meta-syntax layer.
- Consequences: computers only have operational semantics, while humans require denotational semantics.

5.3 Concepts of PL

- The issue actually comes from the fact that some concepts might be very foreign and hard to communicate (which is why programming can be hard, and how the whole section has shown relative limitations

of doing so). Some of these concepts include *thread concurrency*, *streaming data*, *pointer arithmetic*

And so this is why we need aesthetics: to communicate both easy and complicated things, to reduce friction as much as possible. Example: Alan Perlis's Epigrams are poem-like sentences.

6 Hacking

What beauty is there in machine-enforced inscrutability? Particularly, this redirects to the understanding of the machine (e.g. trying to reduce character counts for one-liners).

6.1 History of hacking

Starting with a disambiguation of the term, with a focus on the specific subversion of the machine. Connection to obfuscated code, but with the distinction made that this obfuscation isn't on purpose, but rather due to machine constraints.

6.2 Unreadability and aesthetics

- Example of the one-liners (trying to compress as much as possible, aspect of social competition of who can write it in the densest way)
- Example of the demoscene (trying to extract as much as possible from the machine, along with dual presentation of the work: output, and code walkthrough)

This shows in an extreme way that you need a degree of expert knowledge in order to appreciate it—in this sense, aesthetics are also dependent on pre-existing knowledge.

6.3 Hacking and/or the lack of beauty

Starting from the limited number examples I have found for beauty in hacking, I inquire as to why is there no beauty (or not as much) in hacking? Does there need to be beauty anywhere, or does function not need it? Does it just never need to be read, or returned to? Is a hack, by definition, idiosyncratic, and thus only has its own aesthetic standard?

There doesn't seem to be so many instances of individuals saying "look, this part is beautiful" because it's so focused on what the machine understands; the real beauty is how they make the humans *realize* what the machine *really* understands.

6.4 Computation

What is a computer? What is computation? There are differing approaches, and this allows me to highlight the one in this thesis (that of the formal, symbolic system). Cantell-Smith is quite relevant here, since he explain that things are complicated to explain, but nonetheless intuitive to any serious practitioner of CS.

7 Conclusion

- Aesthetics matter, even in such a highly formal, syntactical, autotelic system as a computer, since they connect a surface-structure with a deep-structure, and act as a bridge between subjectivities.
- There is a complex relationship between abstraction, metaphor and mental model when it comes to understanding programs. Some patterns can help with this task of understanding, and point at a different direction of aesthetics (as manifestation of "the good").
- Concepts to build on going forward: *semantic compression* and *spatio-visual pattern-solving*

The emphasis is placed on the symbolic, cognitive, planning aspects of the arts leads us to give value to the role played by problem-solving, seeing there a model in terms of which the moment-to-moment artist's behavior at work can be described. *An analysis of behavior as a sequence of problem-solving and*

planning activities seems to be most promising [...]" (Goodman, Project Zero)

7.1 Next steps

- More close-reading of more source code, including parts of large-scale, production software (UNIX? LaTeX?)
- Gathering of more hacking program texts and computer science/research program texts.
- More rigorously tie in the analysis of source code poems more tightly with aesthetics (denotation, depictions, labelling, etc.)
- Actually answer the question of whether or not computers "care" about aesthetics.
- Software patterns as a design canon, including the ambivalence of style. And style in general?

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