Cognitive Complexity

YEGOR BUGAYENKO

Lecture #3 out of 24
80 minutes

The slidedeck was presented by the author in this YouTube Video

1. Cyclomatic complexity is highly inaccurate if being compared with code readability evaluated by a human.

"Computational complexity assesses the difficulty of verifying an algorithm's correctness, while psychological complexity assesses human performance on programming tasks."

— Bill Curtis, Sylvia B. Sheppard, Phil Milliman, M. A. Borst, and Tom Love. Measuring the Psychological Complexity of Software Maintenance Tasks With the Halstead and McCabe Metrics. *IEEE Transactions on Software Engineering*, (2):96–104, 1979. doi:10.1109/TSE.1979.234165

Bill Curtis

"By cognitive complexity we mean the <u>mental burden</u> of the persons who have to deal with the class. We <u>assume</u> that it is the, sometimes necessary, high cognitive complexity of a class which causes it to display undesirable external qualities, such as decreased maintainability and testability, or increased fault-proneness."

— Lionel C. Briand and Jürgen Wüst. Integrating Scenario-Based and Measurement-Based Software Product Assessment. *Journal of Systems and Software*, 59(1):3–22, 2001. doi:<u>10.1016/S0164-1212(01)00045-0</u>

LIONEL C. BRIAND
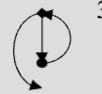
"Cognitive complexity, the <u>new measure</u> for software complexity presented in this paper, is a measure of the cognitive and psychological complexity of software as a human intelligence artifact."

— Jingqiu Shao and Yingxu Wang. A New Measure of Software Complexity Based on Cognitive Weights. *Canadian Journal of Electrical and Computer Engineering*, 28(2):69–74, 2003. doi:<u>10.1109/CJECE.2003.1532511</u>

JINGQIU SHAO

Table 1
Definition of BCSs and their equivalent cognitive weights (W_i)

Category	BCS	Structure	W_i	RTPA notation
Sequence	Sequence (SEQ)		1	$P \rightarrow Q$ Note: Consider only one sequential structure in a component
Branch	If-then-[else] (ITE)		2	$(?exp\ \mathbf{BL} = \mathbf{T}) \rightarrow P$ $\mid (?\sim) \rightarrow Q$
	Case (CASE)		3	$?\ exp\ \mathbf{RT} =$ $0 \rightarrow P_0$ $\mid 1 \rightarrow P_1$ $\mid \dots$ $\mid n{-}1 \rightarrow P_{n-1}$ $\mid else \rightarrow \emptyset$
Iteration	For-do (R_i)		3	$R_{i=1}^{n}(P(i))$
	Repeat-until (R_1)		3	$R_{\geq 1}^{exp\ \mathbf{BL} \neq \mathbf{T}}(P)$

BCS stands for "basic control structure."

"The cognitive weight of software is the degree of difficulty or relative time and effort required for comprehending a given piece of software modelled by a number of BCSs. The total cognitive weight of a software component, W_c, is defined as the sum of the cognitive weights of its q linear blocks composed of individual BCSs."

Source: Jingqiu Shao and Yingxu Wang. A New Measure of Software Complexity Based on Cognitive Weights. *Canadian Journal of Electrical and Computer Engineering*, 28(2):69–74, 2003. doi:10.1109/CJECE.2003.1532511

"Cognitive complexity of software is a product of its architectural and operational complexities on the basis of deductive semantics and the abstract system theory."

— Yingxu Wang. Cognitive Complexity of Software and Its Measurement. In *Proceedings of the 5th International Conference on Cognitive Informatics*, volume 1, pages 226–235. IEEE, 2006. doi:10.1109/COGINF.2006.365701

"We developed an improved cognitive information complexity measure (CICM) that is based on the amount of information contained in the software and encompasses all the major parameters that have a bearing on the difficulty of comprehension or cognitive complexity of software."

— Dharmender Singh Kushwaha and Arun Kumar Misra. Improved Cognitive Information Complexity Measure: A Metric That Establishes Program Comprehension Effort. *ACM SIGSOFT Software Engineering Notes*, 31(5):1–7, 2006

Dharmender Singh Kushwaha

Comparison of Comprehension Time and CICM
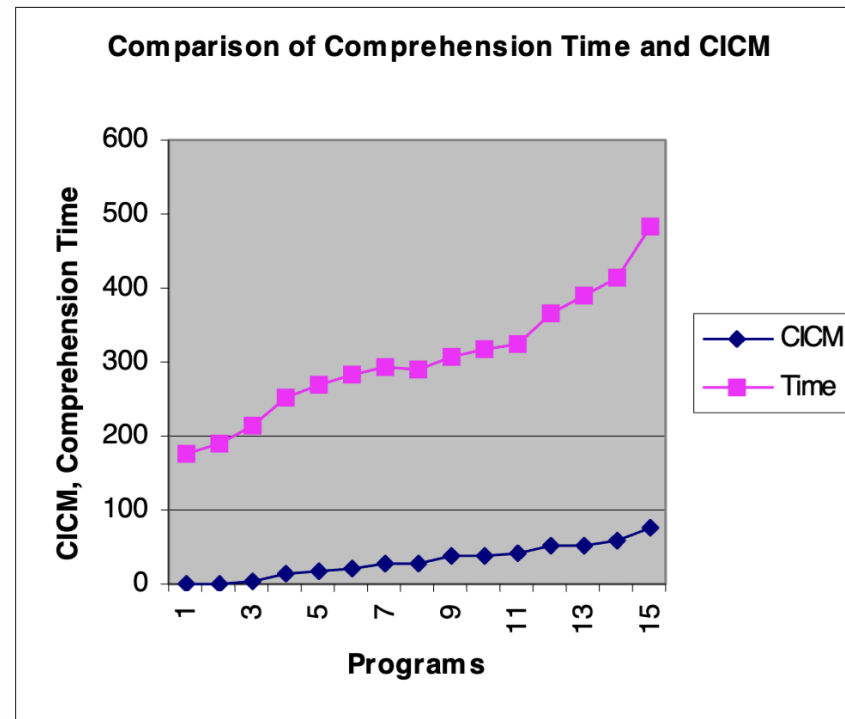
"In a group of 25, each student was given 15 programs. They were asked to read the program and come out with what problem the program addressed. Time required to understand was recorded. The diagram shows that as cognitive information complexity increases, time taken to understand the program also increased."

Source: Dharmender Singh Kushwaha and Arun Kumar Misra. Improved Cognitive Information Complexity Measure: A Metric That Establishes Program Comprehension Effort. *ACM SIGSOFT Software Engineering Notes*, 31(5):1–7, 2006
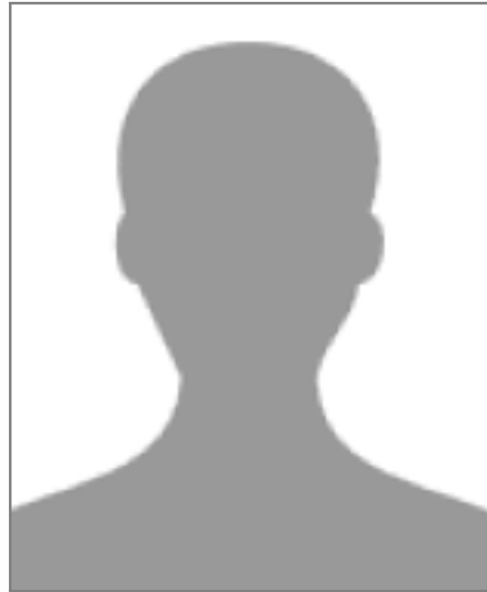
"The cognitive weight of a BCS is measured as the number of ways that BCS can generate some factors that make it difficult to comprehend relative to the sequential BCS, of which the cognitive weight is '1'. The value of total cognitive weights of the software is measured as the number of relative ways that software can generate the combination of factors that make the function and semantics difficult to comprehend."

— Auprasert Benjapol and Yachai Limpiyakorn. Underlying Cognitive Complexity Measure Computation With Combinatorial Rules, 2008

sonarqube

"A guiding principle in the formulation of Cognitive Complexity has been that it should incent <u>good</u> coding practices. That is, it should either ignore or discount features that make code more readable."

— G. Ann Campbell. Cognitive Complexity: An Overview and Evaluation. In *Proceedings of the International Conference on Technical Debt*, pages 57–58, 2018. doi:<u>10.1145/3194164.3194186</u>

Ann Campbell

```
int sumOfPrimes(int max) {              // +1        String getWords(int number) { // +1
  int total = 0;                                       switch (number) {
  OUT: for (int i = 1; i <= max; ++i) { // +1            case 1:                      // +1
    for (int j = 2; j < i; ++j) {       // +1             return "one";
      if (i % j == 0) {                 // +1           case 2:                      // +1
        continue OUT;                                     return "a couple";
      }                                                 case 3:                      // +1
    }                                                     return "a few";
    total += i;                                         default:
  }                                                       return "lots";
  return total;                                         }
}                 // Cyclomatic Complexity 4          }      // Cyclomatic Complexity 4
```

"The mathematical model underlying <u>Cyclomatic Complexity</u> gives these two methods equal weight, yet it is intuitively obvious that the control flow of `sumOfPrimes` is more difficult to understand than that of `getWords`."

Source: G. Ann Campbell. {Cognitive Complexity} — A New Way of Measuring Understandability, 2017

```
int sumOfPrimes(int max) {                          String getWords(int number) {
  int total = 0;                                      switch (number) {              // +1
  OUT: for (int i = 1; i <= max; ++i) { // +1            case 1:
    for (int j = 2; j < i; ++j) {        // +2            return "one";
      if (i % j == 0) {                  // +3        case 2:
        continue OUT;                    // +1          return "a couple";
      }                                               case 3:
    }                                                   return "a few";
    total += i;                                       default:
  }                                                     return "lots";
  return total;                                       }
}                    // Cognitive Complexity 7      }      // Cognitive Complexity 1
```

"The <u>Cognitive Complexity</u> algorithm gives these two methods markedly different scores, ones that are far more reflective of their relative understandability."

Source: G. Ann Campbell. {Cognitive Complexity} — A New Way of Measuring Understandability, 2017

Rubén Saborido

"Different cognitive complexity measures have been proposed to quantify the understandability of a piece of code and, therefore, its maintainability. However, the cognitive complexity metric provided by SonarSource is quickly spreading in the software industry due to the popularity of their well-known static code tools for evaluating software quality."

— Rubén Saborido, Javier Ferrer, Francisco Chicano, and Enrique Alba. Automatizing Software Cognitive Complexity Reduction. *IEEE Access*, 10: 11642–11656, 2022. doi:0.1109/ACCESS.2022.3144743

Cognitive Complexity (CoCo) is supported by a few static analyzers:

- for Java by PMD since 6.22.0
- for Ruby by Rubocop since 0.25 (called "perceived complexity")
- for C++ by CodeClimate
- for JavaScript by ESLint via SonarSource plugin
- for Python by Flake8 via this plugin
- for Rust by Clippy since 1.35.0
- for PHP by PHPCS via this plugin

2. Maybe it's impossible to accurately measure the "<u>perceived</u> complexity" of software?

"We showed that the search for <u>general</u> software complexity measures is doomed to failure."

— Norman Fenton. Software Measurement: A Necessary Scientific Basis. *IEEE Transactions on Software Engineering*, 20(3):199–206, 1994. doi:10.1109/32.268921

Luigi Lavazza

"Being able to find statistical correlations between code <u>understandability</u> and source code <u>measures</u> would be greatly beneficial for the software development process, which involves a great deal of activities involving program <u>comprehension</u>."

— Luigi Lavazza, Abedallah Zaid Abualkishik, Geng Liu, and Sandro Morasca. An Empirical Evaluation of the "Cognitive Complexity" Measure as a Predictor of Code Understandability. *Journal of Systems and Software*, 197:111561, 2023. doi:<u>10.1016/j.jss.2022.111561</u>

3. Social code analysis: we analyze the author(s) of the code, not only the code itself.

"Social code analysis enriches our understanding of the code quality by overlaying a developer's behavior with the structural analysis of the code."

— ThoughtWorks. Social Code Analysis.
https://www.thoughtworks.com/en-de/radar/techniques/social-code-analysis, mar 2017. [Online; accessed 09-10-2024]

"BrainMaster Technologies (USA) sells this "Freedom 20R" EEG head set for $31,025. A similar device you can get from Neiry (Russia), for 3% of this price."

"We propose the use of biofeedback code highlighting techniques to provide online programmer's warnings for potentially problematic code lines that may need a second look at (to remove possible bugs)."

— Ricardo Couceiro, Raul Barbosa, Joáo Duráes, Gonçalo Duarte, Joáo Castelhano, Catarina Duarte, Cesar Teixeira, Nuno Laranjeiro, Júlio Medeiros, Paulo Carvalho, et al. Spotting Problematic Code Lines Using Nonintrusive Programmers' Biofeedback. In *Proceedings of the 30th International Symposium on Software Reliability Engineering (ISSRE)*, pages 93–103. IEEE, 2019. doi:10.1109/ISSRE.2019.00019

The following Java code has an obvious but hard to spot functional defect:

```java
public class AverageCalculator {                            // LOW
  public static void main(String[] args) {                  // LOW
    int[] numbers = {10, 20, 30, 40, 50};                   // LOW
    System.out.println("Average: " + avg(numbers));         // MEDIUM
  }                                                         // LOW
  static double avg(int[] nums) {                           // LOW
    double sum = 0;                                         // MEDIUM
    for (int i = 0; i <= nums.length; i++)                 // HIGH
      sum += nums[i];                                       // HIGH
    return sum / nums.length;                               // MEDIUM
  }                                                         // LOW
}                                                           // LOW
```

The "cognitive state code annotations" are on the right side of the code, as Java comments, indicating the level of brain activity at the moment of writing the particular line of code.

"The EEG results reveal evidence of mental effort saturation as code complexity increases. Conversely, the classic software complexity metrics do not accurately represent the mental effort involved in code comprehension."

— Júlio Medeiros, Ricardo Couceiro, Gonçalo Duarte, João Durães, João Castelhano, Catarina Duarte, Miguel Castelo-Branco, Henrique Madeira, Paulo de Carvalho, and César Teixeira. Can EEG Be Adopted as a Neuroscience Reference for Assessing Software Programmers' Cognitive Load? *Sensors*, 21(7): 2338, 2021. doi:10.3390/s21072338

References

Auprasert Benjapol and Yachai Limpiyakorn. Underlying Cognitive Complexity Measure Computation With Combinatorial Rules, 2008.

Lionel C. Briand and Jürgen Wüst. Integrating Scenario-Based and Measurement-Based Software Product Assessment. *Journal of Systems and Software*, 59(1):3–22, 2001. doi:10.1016/S0164-1212(01)00045-0.

G. Ann Campbell. {Cognitive Complexity} — A New Way of Measuring Understandability, 2017.

G. Ann Campbell. Cognitive Complexity: An Overview and Evaluation. In *Proceedings of the International Conference on Technical Debt*, pages 57–58, 2018. doi:10.1145/3194164.3194186.

Ricardo Couceiro, Raul Barbosa, Joáo Duráes, Gonçalo Duarte, Joáo Castelhano, Catarina Duarte, Cesar Teixeira, Nuno Laranjeiro, Júlio Medeiros, Paulo Carvalho, et al. Spotting Problematic Code Lines Using Nonintrusive Programmers' Biofeedback. In *Proceedings of the 30th International Symposium on Software Reliability Engineering (ISSRE)*, pages 93–103. IEEE, 2019. doi:10.1109/ISSRE.2019.00019.

Bill Curtis, Sylvia B. Sheppard, Phil Milliman, M. A. Borst, and Tom Love. Measuring the Psychological Complexity of Software Maintenance Tasks With the Halstead and McCabe Metrics. *IEEE Transactions on Software Engineering*, (2):96–104, 1979. doi:10.1109/TSE.1979.234165.

Norman Fenton. Software Measurement: A Necessary Scientific Basis. *IEEE Transactions on Software Engineering*, 20(3):199–206, 1994. doi:10.1109/32.268921.

Dharmender Singh Kushwaha and Arun Kumar Misra. Improved Cognitive Information Complexity Measure: A Metric That Establishes Program Comprehension Effort. *ACM SIGSOFT Software Engineering Notes*, 31(5):1–7, 2006.

Luigi Lavazza, Abedallah Zaid Abualkishik, Geng Liu,

and Sandro Morasca. An Empirical Evaluation of the "Cognitive Complexity" Measure as a Predictor of Code Understandability. *Journal of Systems and Software*, 197:111561, 2023. doi:10.1016/j.jss.2022.111561.

Júlio Medeiros, Ricardo Couceiro, Gonçalo Duarte, João Durães, João Castelhano, Catarina Duarte, Miguel Castelo-Branco, Henrique Madeira, Paulo de Carvalho, and César Teixeira. Can EEG Be Adopted as a Neuroscience Reference for Assessing Software Programmers' Cognitive Load? *Sensors*, 21(7):2338, 2021. doi:10.3390/s21072338.

Rubén Saborido, Javier Ferrer, Francisco Chicano, and Enrique Alba. Automatizing Software Cognitive Complexity Reduction. *IEEE Access*, 10: 11642–11656, 2022. doi:0.1109/ACCESS.2022.3144743.

Jingqiu Shao and Yingxu Wang. A New Measure of Software Complexity Based on Cognitive Weights. *Canadian Journal of Electrical and Computer Engineering*, 28(2):69–74, 2003. doi:10.1109/CJECE.2003.1532511.

ThoughtWorks. Social Code Analysis. https://www.thoughtworks.com/en-de/radar/techniques/social-code-analysis, mar 2017. [Online; accessed 09-10-2024].

Yingxu Wang. Cognitive Complexity of Software and Its Measurement. In *Proceedings of the 5th International Conference on Cognitive Informatics*, volume 1, pages 226–235. IEEE, 2006. doi:10.1109/COGINF.2006.365701.