

Acyclic complexity (draft)

Abstract. In this paper we propose a linear-quadratic code complexity measure from the perspective of testing with the conjecture of independent enclosed scopes. The new measure covers condition collocation, repeated and nested structures.

1 Introduction

A Program consist of a sequences of instructions. The instructions can be categorized into syntax, logic and arithmetic determining the program control flow.

Software complexity is related with modularity, coupling and cohesion hence quality. 40% to 80% of software costs are traced on maintenance and approximatly 40% on fixing defects [SG11].

Analysing code complexity helps to identify risk, finds potential defects to test critical functionality in detail, increase quality, cohesion and decrease maintainance [RB11].

2 Existing measures

Cyclomatic complexity (CC) has been widely discussed by various authors. The most used metric has been formulated by Thomas J. McCabe in 1976 [McC76].

$$m = e - n + 2 \quad (1)$$

Where, e = the amount of edges. n = the amount of nodes.

CC is linear in it's nature and correlation with lines of code (LOC), which is why Graylin JAY et al. [al.09] are suggesting to implement LOC as complexity measure.

Mir Muhammd Suleman Sarwar et al. [MMSS13] are pointing out that it neither takes into account the difference between combined decisions, elementary conditions nor repeating structures. Their adaptation of CC includes loop iterations

$$V(G)^* = V(G) + \prod_{i=1}^n P_i$$

$$P_i = U_i - L_i + 1$$

Where, P_i = No. of iterations of i th loop. U_i = upper bound of i th loop. L_i = lower bound of i th loop and $V(G)^*$ = adjusted cyclomatic complexity for any control flow graph "G". The measure combines control flow and statements exercised.

Brian A. Nejme. NPATH [Nej88] TODO.

Tevfik et al. [LB15] are providing a reasonable complutable measure: asymptotic path complexity covering nested structures and loops in comparison with CC and NPATH. TODO

2.1 Coverage

Test coverage metrics are providing quantitative representation of tested structures. The approach is to maximize coverage while minimizing testing effort. Each condition branches the flow into two control sub-paths, and determines the progression of the programm. The path of an isolated decision d_j thereby is given due to decisions and conditions (MC/DC) [RB11]. Let's define a condition c_j and it's path $\gamma: C \times \Sigma \rightarrow C^*$

$$\Sigma = \{true, false\}$$

$$C = \{c_0, c_1, c_2, c_3, \dots, c_n\}, c_i \mapsto \Sigma$$

$$\varepsilon: C \rightarrow \Sigma \times C$$

$$D \subseteq \{C^*, S, E\}; d_i \in D$$

The transition function *alpha*

$$\alpha: D \times \Sigma^* \rightarrow \Sigma \times D$$

and the transition \vdash

$$\vdash \subseteq (\Sigma^* \times D \times \Sigma) \times (\Sigma^* \times D \times \Sigma)$$

The possible combinations of conditions on γ are arising through c_j 's preceeding and succeeding condition flow. An acyclic transition path through c_j is described due to passing each condition once

$$P_j = (v_i, d_i, b_i), \dots \vdash (v_j, d_j, b_j) \vdash^* (v_n, d_n, b_n)$$

$$= (c_i, b_i), \dots \vdash (c_j, b_j) \vdash^* (c_n, b_n)$$

where

$$\alpha(d_n, v_n) \mapsto E$$

with the mantle

$$P = (b_i, v_i, d_i) \vdash^* (b_n, v_n, d_n)$$

3 Acyclic complexity

Instead of combining arithmetic and logic we propose a metric reflecting the logical test effort indicated by the amount of paths. The concept of basic paths described by [McC76] neglects loops and nesting. 100% sub-path combination coverage q is intricate due to exponential effort. Conditions are providing the logical structure of programs (Listing 1-12). Loops and recursions are construed due to their invariant and boundary [RB11], which is why their quantitative iteration increases inclination not path length. Let's define the inductive start of independent

$$\begin{aligned} \alpha_i = & (c_0, true) \rightarrow (c_1), (c_0, false) \rightarrow (c_1), \\ & (c_1, true) \rightarrow (E), (c_1, false) \rightarrow (E) \end{aligned}$$

and dependent structures

$$\begin{aligned} \alpha_d = & (c_0, true) \rightarrow (E), (c_0, false) \rightarrow (c_1), \\ & (c_1, true) \rightarrow (E), (c_1, false) \rightarrow (E) \end{aligned}$$

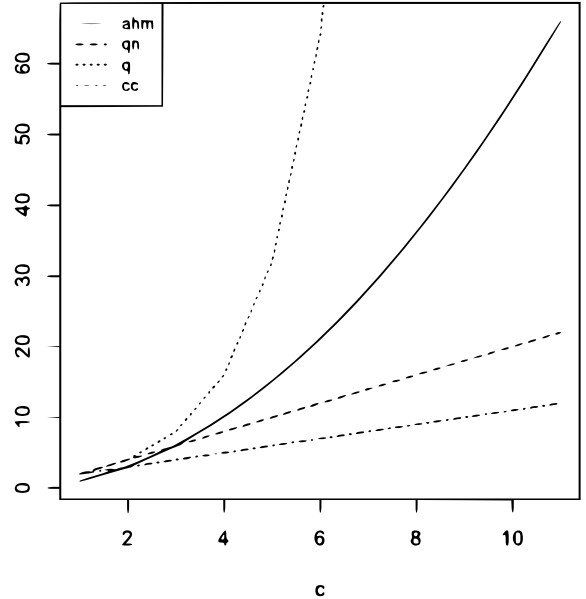
The isolated condition paths are delineate $\log(2^n)$ subset of all q transition combinations from beginning to end. If we draw the spanning trees the first structure consists of four paths, where the second consists of three complete isolated paths.

The nesting of loops and conditions doesn't increase testing effort from the perspective of parameter combinations, the amount of paths yet decreases reciprocal with nesting. The perceived complexity of dependent structures increases contrary due to remembering previous preceeding conditions (Table 2).

Table 1. Condition collocation bound

| C | loc | | q | | q2 | | cc | ahm | |
|-----|-----|-------|-----|--------------------|-----|-----|----|------|-----------------|
| | min | max | min | max | min | max | | max | min |
| 1 | 1 | l_0 | 2 | 2 | 2 | 2 | 2 | 1 | $\frac{1}{2}$ |
| 2 | 1 | l_1 | 3 | 4 | 3 | 4 | 3 | 3 | 1 |
| 3 | 1 | l_2 | 4 | 8 | 4 | 6 | 4 | 6 | $\frac{3}{2}$ |
| 4 | 1 | l_3 | 5 | 16 | 5 | 8 | 5 | 10 | 2 |
| 5 | 1 | l_4 | 6 | 32 | 6 | 10 | 6 | 15 | $2\frac{1}{2}$ |
| 6 | 1 | l_5 | 7 | 64 | 7 | 12 | 7 | 21 | 3 |
| 7 | 1 | l_6 | 8 | 128 | 8 | 14 | 8 | 28 | $3\frac{1}{2}$ |
| ... | | | | | | | | | |
| 9 | 1 | l_7 | 10 | 512 | 10 | 18 | 10 | 45 | $4\frac{1}{4}$ |
| ... | | | | | | | | | |
| 19 | 1 | l_8 | 20 | 524288 | 20 | 38 | 20 | 190 | $9\frac{1}{2}$ |
| ... | | | | | | | | | |
| 49 | 1 | l_9 | 50 | $\sim 5 * 10^{14}$ | 50 | 98 | 50 | 1225 | $24\frac{1}{2}$ |

Fig. 1. Upper Bound



Listing 1. plain singular

```
if (-1<1) { }
```

Listing 2. orthogonal dual

```
if (3>1 && 0<k) { }
```

Listing 3. tertiary orthogonal

```
if (2>1 && 7>k && 10>m) { }
```

Listing 4. orthogonal dual

```
if (2>1 || 0<k) { }
```

Listing 5. orthogonal dual nested

```
if (0<1) {
    ...
    if (2>k) { }
    ...
}
```

Listing 6. tertiary orthogonal nested

```
if (0<1 && 4>k) {
    ...
    if (11>m) { }
    ...
}
```

Listing 7. tertiary

```
if (2>1 && 0<k || 4>m) { }
```

Listing 8. parallel

```
if (2>1) { }
...
if (8>k) { }
```

Listing 9. tertiary parallel identical scope

```
if (2>1 || 0<k || 4>m) { }
```

Listing 10. tertiary orthogonal nested

```
if (2>1) {
    ...
    if (8>k) {
        ...
        if (2<m) { }
```

| Listing | C | loc | q | q ₂ | cc | ahm |
|---------|---|-----|---|----------------|----|-----------------|
| 1 | 1 | 1 | 2 | 1 | 2 | 1 |
| 2 | 2 | 1 | 3 | 3 | 3 | 1 $\frac{1}{2}$ |
| 3 | 3 | 1 | 4 | 5 | 4 | 1 $\frac{5}{6}$ |
| 4 | 2 | 1 | 3 | 3 | 3 | 2 |
| 5 | 2 | 5 | 3 | 3 | 3 | 2 |
| 6 | 3 | 5 | 4 | 5 | 4 | 2 $\frac{1}{2}$ |
| 7 | 3 | 1 | 5 | 5 | 4 | 2 $\frac{1}{2}$ |
| 8 | 2 | 3 | 4 | 2 | 3 | 3 |
| 9 | 3 | 1 | 4 | 5 | 4 | 3 |
| 10 | 3 | 8 | 4 | 5 | 4 | 3 |
| 11 | 3 | 7 | 5 | 4 | 4 | 4 |
| 12 | 3 | 6 | 6 | 4 | 4 | 4 |
| 13 | 3 | 5 | 8 | 3 | 4 | 6 |

```
    ...
} }
```

Listing 11. singular nested parallel

```
if (0<1) {
    ...
    if (4>k) { }
    ...
    if (8>m) { }
    ...
}
```

Listing 12. orthogonal singular parallel

```
if (0<1) {
    ...
    if (8>k) { }
    ...
}
if (2<m) { }
```

Listing 13. tertiary parallel different scope

```
if (-4<1) { }
...
if (4<k) { }
...
if (8<m) { }
```

Table 3. α_i flow matrix, $q_2(\alpha_i) = 2$

| | s | c_0 | c_1 | e |
|-------|---|-------|-------|-------|
| s | | t | | |
| c_0 | | | (t,f) | |
| c_1 | | | | (t,f) |
| e | | | | |

Table 4. α_d flow matrix, $q_2(\alpha_d) = 3$

| | s | c_0 | c_1 | e |
|-------|---|-------|-------|-------|
| s | | t | | |
| c_0 | | | f | t |
| c_1 | | | | (t,f) |
| e | | | | |

The exponential amount of condition combinations 2^n is dissected due to exclusiv control flow q .

$$\begin{aligned} n &= |C| \\ 2^n &\leq q \leq n+1 \end{aligned} \quad (2)$$

. When every condition is isolated the amount of condensed edges (enclosed scope paths) q_2 in the condition flow matrix represents an intuitive measure indicating the condition flow (Table 2, 1, 3, 4).

The lower and upper bounds of possible isolated condensed condition transition paths are

$$2 * n \geq q_2 \geq n + 1 \quad (3)$$

$$C_e \subset C; \quad m_u = |C| + |C_e|$$

with $C_e \subset C$ nested conditions. The metric m_u is undifferentiated regarding condition nesting level. The subjective perception of increased complexity due to nesting and scope combination isn't taken care of, which is why we define the condition nesting function $\lambda(c_i)$

$$\begin{aligned} \frac{n}{2} &< m_{ah} \leq \frac{n(n+1)}{2} \\ m_{ah} &= \sum \lambda(c_i) = \sum_{i=0}^n \frac{r_i}{e_i} \end{aligned} \quad (4)$$

Fig. 2. Apache Tomcat 9.0.13
Apache Tomcat Difference McCabe - Acyclic Complexity

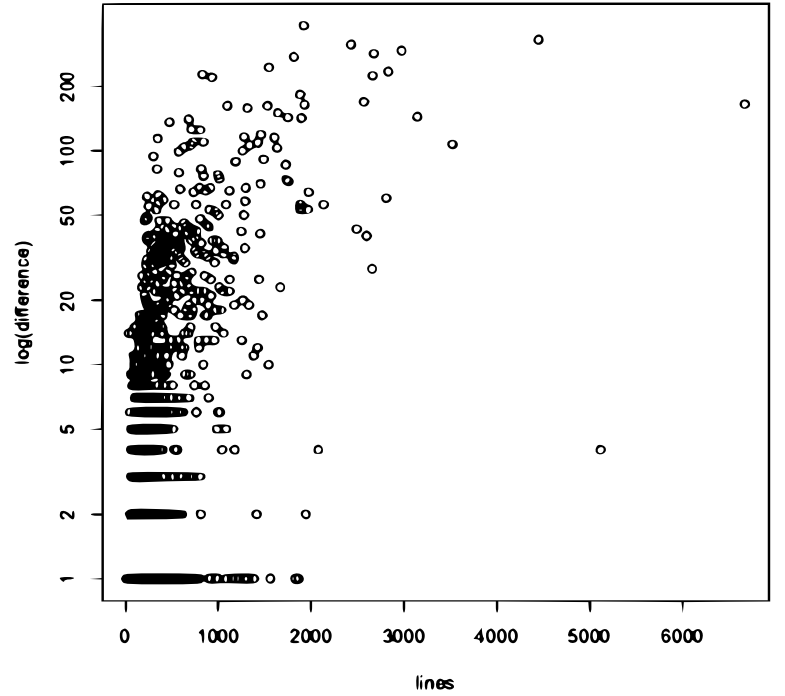
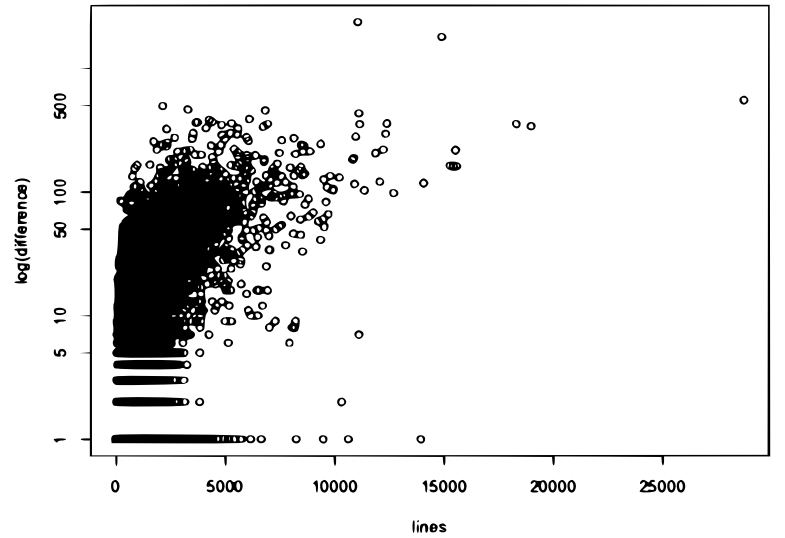


Fig. 3. Linux Kernel 4.14.79
Linux-4.14.79 Difference McCabe - Acyclic Complexity



Measuring the complexity of current open source projects provided a logarithmic asymptotic difference when investigating the increase of complexity correlated with the lines of code Fig. (2), (3). Especially the significant variance is apparent.

Table 5. Complexity Risk [Cha05]

| cc | ahm | Risk |
|-------|---------|-----------------------|
| 1-10 | 1-21 | basic program |
| 11-20 | 22-50 | knotty, moderate risk |
| 21-50 | 51-1225 | circuitous, high risk |

4 Conclusion

The proposed acyclic linear-quadratic complexity measure (4) reflects the logical test effort of condensed isolated condition paths (enclosed scopes). It provides an reasonable absolute value concerning control flow, nesting and collocation according with subjective perception.

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