An Empirical Study of C to Rust Translation using Local Large-Language Models

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Desire to rewrite (legacy) code in Rust for improved security guarantees.

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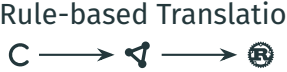

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Existing approaches leverage proprietary LLMs (ChatGPT, Claude)

- Larger context widows
- Cloud based (non-private)

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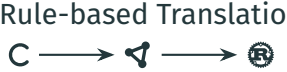

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What happens in a **resource constrained** setting?

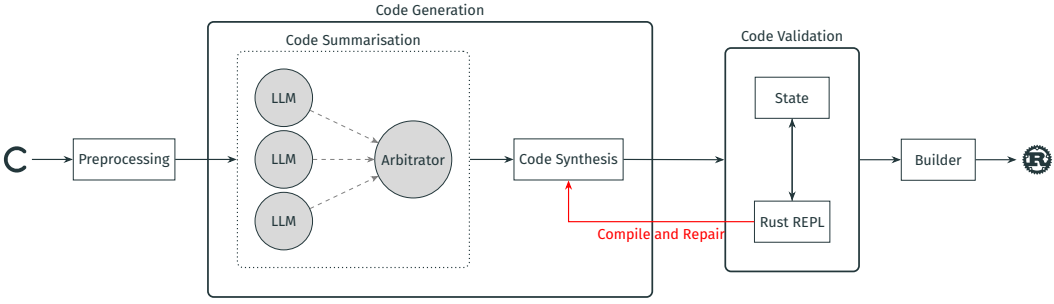
Contributions

OXIDATION - a C2Rust translation framework for resource constrained settings

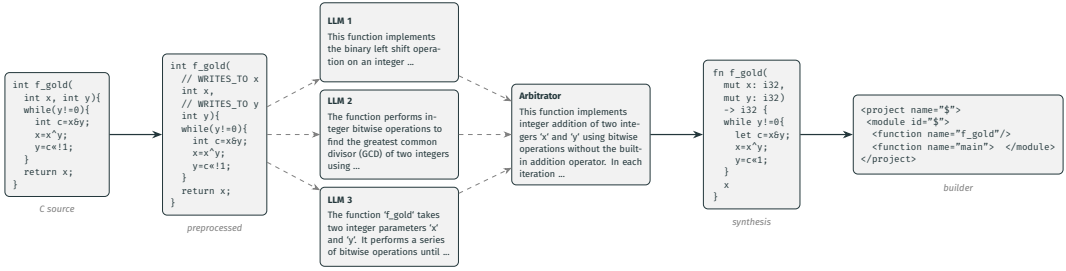
Two new techniques for context management:

1. Arbitration for structuring code summarisation and generation
2. Incremental composition and validation of generated code fragments

Oxidation Overview



Code Arbitration



Goal: Allow the Arbitrator to compensate for what other models miss

- Specialise summarisations on different properties

Reduced context size in comparison to thinking / planning modes.

Evaluation

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1. Evaluate the runtime and accuracy of the OXIDATION pipeline for different local LLM configurations.
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Evaluation Dataset: Transcoder-IR

- Samples contain a fgold() baseline, LLM generates ffilled()
- Preprocessed to remove invalid C and any CPP leaving 425/698 samples
- Models Used: Llama3.2:3b, Mistral:7b, Gemma3:4b, Qwen3:4b

Results: Average Pipeline Runtime

Condition	Correct Translations	Tokens In	Tokens Out	Time Per Prompt
llama3.2:3b (DT)	92	261	63	2.00s
mistral:7b (DT)	66	280	157	5.00s
mistral:7b (ARB)	267	396	222	8.00s
qwen3:4b (DT)	389	4439	128	1m53.00s
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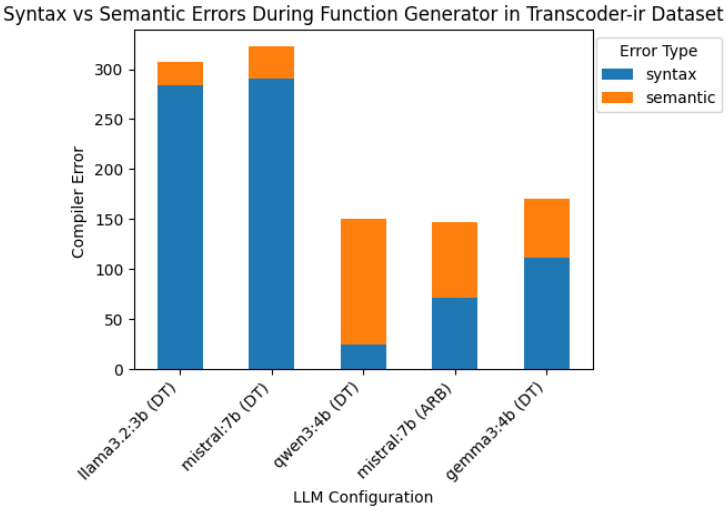
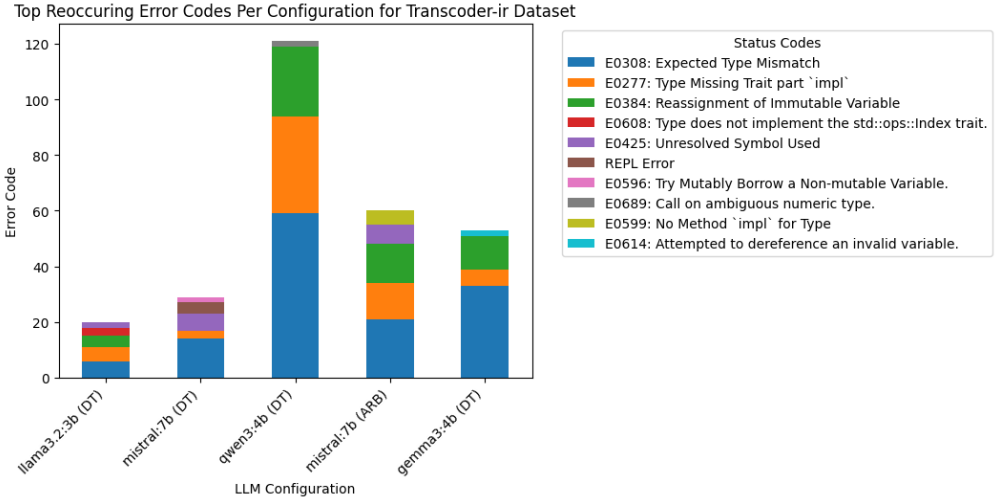
Results: Syntax vs Semantic Errors



Results: Reoccuring compilation errors



Conclusions

We present OXIDATION, a translation pipeline for resource constrained LLMs.

Paper & Code

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Function level results over the Transcoder-IR dataset suggest:

- 3× increase in translation success for non-thinking models using arbitration
- 31% drop in translation success, but a 5× perf gain for thinking models.

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Future Work:

- Designing code translation for agentic software patterns
- Applying these techniques to different categories of software

Paper & Code

References i

[1] Xuemeng Cai et al. *RustMap: Towards Project-Scale C-to-Rust Migration via Program Analysis and LLM*. Mar. 22, 2025. DOI: 10.48550/arXiv.2503.17741. arXiv: 2503.17741[cs]. URL: http://arxiv.org/abs/2503.17741 (visited on 06/02/2025).

[2] Yufeng Du et al. *Context Length Alone Hurts LLM Performance Despite Perfect Retrieval*. Oct. 6, 2025. DOI: 10.48550/arXiv.2510.05381. arXiv: 2510.05381[cs]. URL: http://arxiv.org/abs/2510.05381 (visited on 10/31/2025).

References ii

[3] Yifei Gao et al. *PR2: Peephole Raw Pointer Rewriting with LLMs for Translating C to Safer Rust*. May 9, 2025. DOI: 10.48550/arXiv.2505.04852. arXiv: 2505.04852[cs]. URL: http://arxiv.org/abs/2505.04852 (visited on 05/12/2025).

References iii

[4] Jaemin Hong and Sukyoung Ryu. **"To Tag, or Not to Tag: Translating C's Unions to Rust's Tagged Unions".** In: *Proceedings of the 39th IEEE/ACM International Conference on Automated Software Engineering*. ASE '24: 39th IEEE/ACM International Conference on Automated Software Engineering. Sacramento CA USA: ACM, Oct. 27, 2024, pp. 40–52. ISBN: 979-8-4007-1248-7. DOI: 10.1145/3691620.3694985. URL: https://dl.acm.org/doi/10.1145/3691620.3694985 (visited on 05/12/2025).

[5] Immunant and Galois. *C2Rust: Migrate C code to Rust*. 2022. URL: https://github.com/immunant/c2rust.

References iv

[6] Vikram Nitin et al. *C2SaferRust: Transforming C Projects into Safer Rust with NeuroSymbolic Techniques.* Jan. 24, 2025. DOI: 10.48550/arXiv.2501.14257. arXiv: 2501.14257[cs]. URL: http://arxiv.org/abs/2501.14257 (visited on 02/10/2025).

[7] Manish Shetty et al. *Syzygy: Dual Code-Test C to (safe) Rust Translation using LLMs and Dynamic Analysis.* Dec. 21, 2024. DOI: 10.48550/arXiv.2412.14234. arXiv: 2412.14234[cs]. URL: http://arxiv.org/abs/2412.14234 (visited on 01/02/2025).

References v

[8] Chaofan Wang et al. *EvoC2Rust: A Skeleton-guided Framework for Project-Level C-to-Rust Translation*. Oct. 10, 2025. DOI: 10.48550/arXiv.2508.04295. arXiv: 2508.04295[cs]. URL: http://arxiv.org/abs/2508.04295 (visited on 10/31/2025).

[9] Aidan Z. H. Yang et al. *VERT: Verified Equivalent Rust Transpilation with Large Language Models as Few-Shot Learners*. May 25, 2024. DOI: 10.48550/arXiv.2404.18852. arXiv: 2404.18852[cs]. URL: http://arxiv.org/abs/2404.18852 (visited on 11/25/2024).

References vi

[10] Hanliang Zhang et al. **“Scalable, Validated Code Translation of Entire Projects using Large Language Models”.** In: *Proceedings of the ACM on Programming Languages* 9 (PLDI June 10, 2025), pp. 1616–1641. ISSN: 2475-1421. DOI: 10.1145/3729315. URL: https://dl.acm.org/doi/10.1145/3729315 (visited on 10/31/2025).

[11] Tianyang Zhou et al. *LLM-Driven Multi-step Translation from C to Rust using Static Analysis.* Mar. 18, 2025. DOI: 10.48550/arXiv.2503.12511. arXiv: 2503.12511[cs]. URL: http://arxiv.org/abs/2503.12511 (visited on 05/23/2025).

Verification: I/O Equivilence

Category	Llama3	Mistral 7B	Qwen3 4B	Arb Mistral 7B	Gemma3 4B
No Translation	275	359	30	158	146
ABI Incompatible	7	39	179	32	131
Runtime Timeout	0	1	0	0	0
Missing Rust Import	3	0	1	0	1
C Compilation Error (Clang)	2	3	4	7	7
Function Signature Mismatch	90	0	6	139	29
Test Fail: Pointer Related	14	8	50	18	26
Test Fail: Runtime Exception	1	0	0	1	0
Test Fail: IO Mismatch	12	8	35	33	22
Test Pass	17	4	120	35	63

Results: Impact of Arbitration Summaries

Original C

```c
int f_gold ( int x ) {
  int m = 1;
  while ( x & m ) {
    x = x ^ m;
    m <<= 1;
  }
  x = x ^ m;
  return x;
}
```

3b LLM

```rust
let mut x = 10u32; let
    mut y = 2u32;
while y != 0 {
int carry = x & y;
x = x ^ y;
y = (y - carry) / 2;
}
x;
```

4b & Thinking LLM

```rust
fn f_gold(x: i32, y: i32)
    -> i32 {
    let mut x = x;
    let mut y = y;
    while y != 0 {
        let carry = x & y
            ;
        x = x ^ y;
        y = carry << 1;
    }
    x
}
```

Arb w/out Thinking

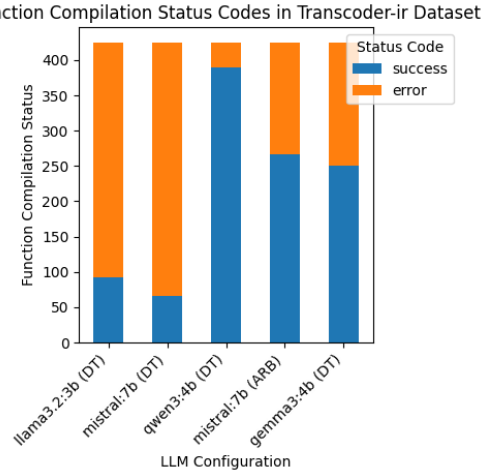
```rust
fn f_gold(mut x: u64, mut
    y: u64) -> u64 {
    loop {
        let carry = x & y
            ;
        x ^= y;
        y <<= 1;
        if y == 0 {
            break;
        }
        y |= carry;
    }
    x
}
```

Arb w/ Thinking

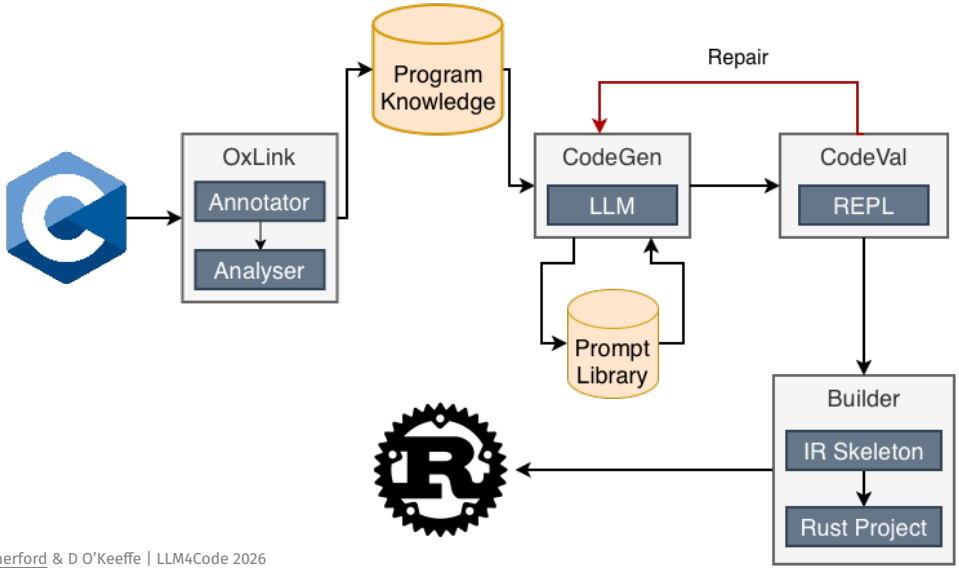
```rust
fn f_gold(mut x: i32, mut
    y: i32) -> i32 {
    while y != 0 {
        let carry = x & y
            ;
        x = x ^ y;
        y = carry << 1;
    }
    x
}
```

Figure 1: Translation for ADD_TWO_NUMBERS_WITHOUT_USING_ARITHMETIC_OPERATORS

Results: Function Compilation Status



System Overview



Arbitration