

TaMaRa:

An automated triple modular redundancy EDA flow for Yosys

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Prepared for YosysHQ and Sandia National Laboratories

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Background



About me



Matt Young, 21 years old from Brisbane, Australia.

Graduated Bachelor of Computer Science earlier in 2024 from the University of Queensland.

Currently studying Bachelor of Computer Science (Honours) at UQ, which includes a one year research thesis.

Passionate about digital hardware design, embedded systems, high performance/low-level software/hardware. Might take up a PhD in future :)

Motivation

Fault tolerant computing is important for safety critical sectors (aerospace, defence, medicine, etc.)

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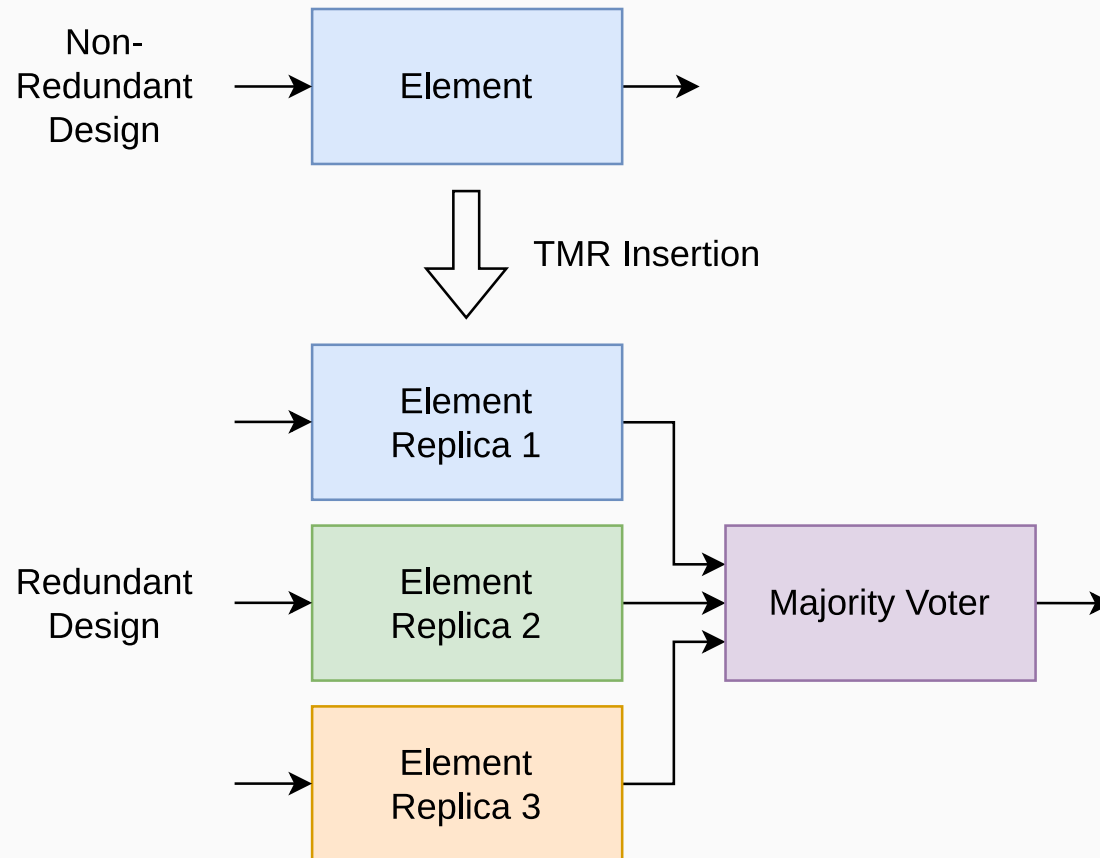
Even in terrestrial applications, SEUs can still occur

- Must be mitigated for high reliability applications

ASICs and FPGAs commonly deployed in space (and on Earth)... but protection from SEUs remains expensive!

RAD750 CPU [\[1\]](#) is commonly used, but costs >\$200,000 USD [\[2\]](#)!

Triple Modular Redundancy



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Can we automate it?

TaMaRa methodology

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- Proprietary vendor tools (Synopsys, Cadence, Xilinx, etc) immediately discarded
- Can't be extended to add custom passes

Two main paradigms:

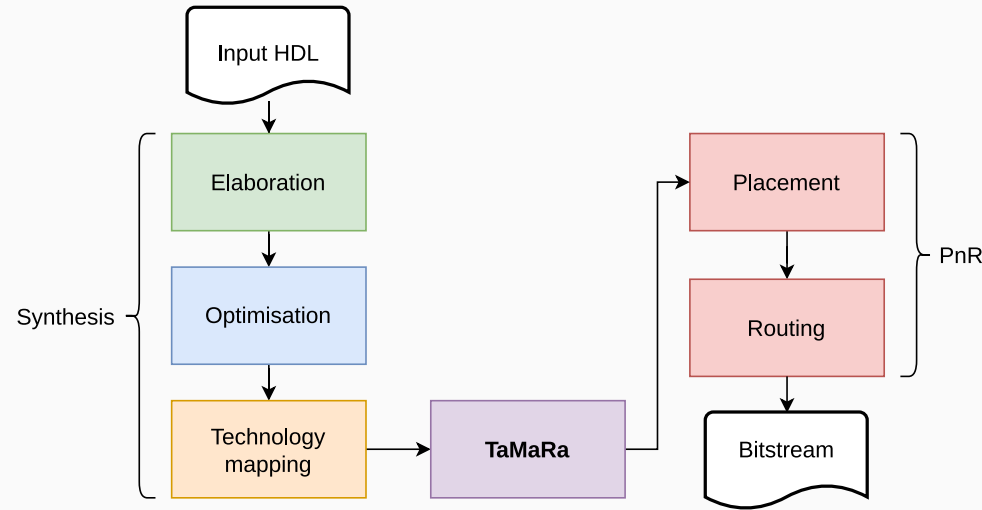
- **Design-level approaches** (“thinking in terms of HDL”)
 - Kulis [\[4\]](#), Lee [\[5\]](#)
- **Netlist-level approaches** (“thinking in terms of circuits”)
 - Johnson [\[6\]](#), Benites [\[7\]](#), Skouson [\[8\]](#)

The TaMaRa algorithm

TaMaRa will mainly be netlist-driven, using Johnson's [6] voter insertion algorithm.

Also aim to propagate a (* triplicate *) HDL annotation to select TMR granularity (similar to Kulis [4]).

Runs after techmapping (i.e. after abc in Yosys)



The TaMaRa algorithm

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Why netlist driven with the `(* triplicate *)` annotation?

- Removes the possibility of Yosys optimisation eliminating redundant TMR logic
- Removes the necessity of complex blackboxing logic and trickery to bypass the normal design flow
- Cell type shouldn't matter, TaMaRa targets FPGAs and ASICs
- Still allows selecting TMR granularity - **best of both worlds**

Comprehensive verification procedure using formal methods, simulation and fuzzing.

Driven by SymbiYosys tools *eqy* and *mcy*

- In turn driven by theorem provers/SAT solvers

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Also considering Beltrame's verification tool [\[9\]](#), and other literature on TMR formal verification.

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Idea:

1. Use Verismith [\[10\]](#) to generate random Verilog RTL.
2. Run TaMaRa synthesis end-to-end.
3. Use formal equivalence checking to verify the random circuits behave the same before/after TMR.

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Problem: Mutation

- We need valid testbenches for these random circuits, how would we generate that?
- Under active research in academia (may not be possible at the moment)

We want to simulate an SEU environment.

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Use one of Verilator, Icarus Verilog or Yosys' own cxxrtl to simulate a full design.

- Each simulator has different trade-offs
- Currently considering picorv32 or Hazard3 as the DUT
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Concept:

- Iterate over the netlist, randomly consider flipping a bit every cycle
- Write a self-checking testbench and ensure that the DUT responds correctly

Technical implementation

Implemented in C++20, using CMake.

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Run `tamara_propagate` after `read_verilog` to propagate the `(* triplicate *)` annotations.

Run `tamara_tmr` after techmapping to perform triplication and voter insertion (add TMR).

Current status & future

Current status

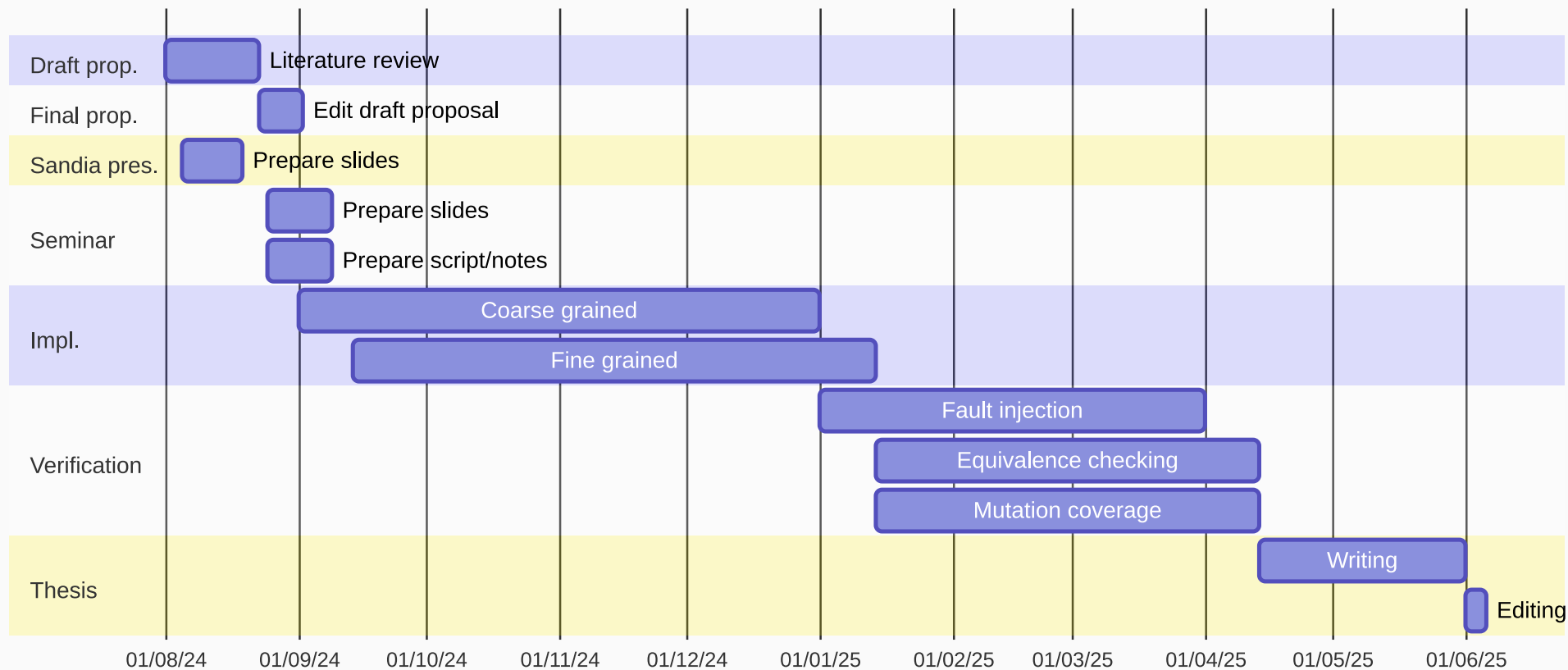
Mostly focused around literature reviews, scoping out the problem, formulating requirements, etc.

Programming expected to start in the next 1-2 weeks.

Skeleton plugin does exist with CMake/Ninja-based toolchain.

The future

TaMaRa Project Plan



This will be implemented for my Honours thesis over the next 1 year.

- Honours is kind of like mini masters, it's an Australia-specific thing.
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Programming hopefully finished *around* February 2025, verification by April 2025.

Ideally, TaMaRa will be released open-source under MPL 2.0.

- Pending university IP shenanigans...

Conclusion

- TaMaRa: Automated triple modular redundancy EDA flow for Yosys
- Fully integrated into Yosys suite
- Takes any circuit, helps to prevent it from experiencing SEUs by adding TMR
- Netlist-driven algorithm based on Johnson's work [\[6\]](#)
- **Key goal:** "Click a button" and have any circuit run in space/in high reliability environments!

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Thank you! Any questions?