PROMATCH: Extending the Reach of Real-time MWPM with Adaptive Pre-Decoding for Quantum Error Correction Decoding

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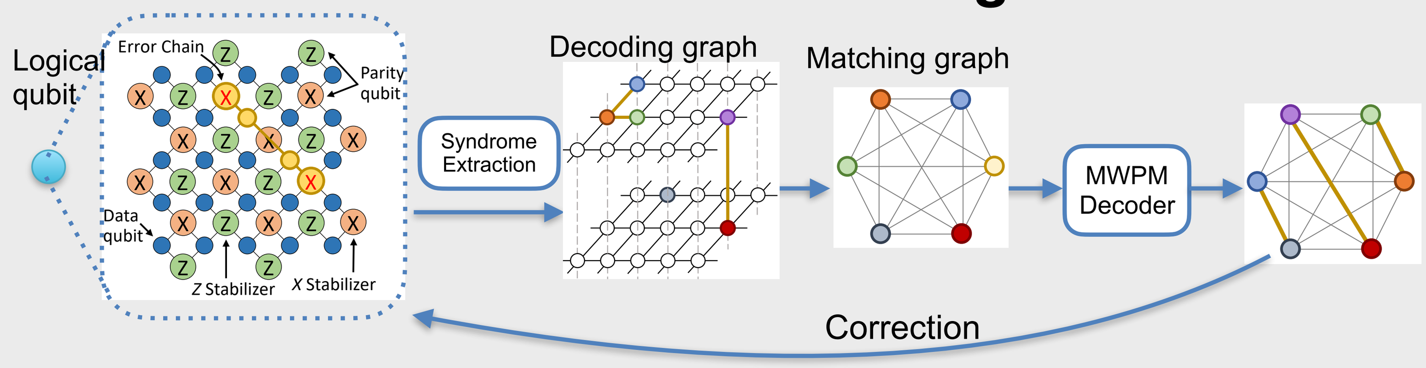
Quantum Computers are Noisy

The main barrier of running promising applications on quantum computers is their inherent noise in the device level.

Current Physical Error Rate	Required Error Rate
$\approx 10^{-4}$ to 10^{-3}	$< 10^{-12}$

Quantum Error Correction (QEC) is required for forming fault-tolerant logical qubits from multiple physical qubits.

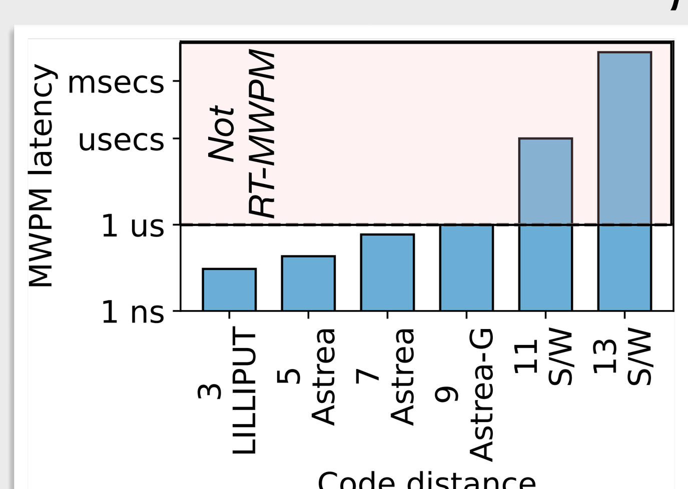
Surface Code and the Decoding Problem

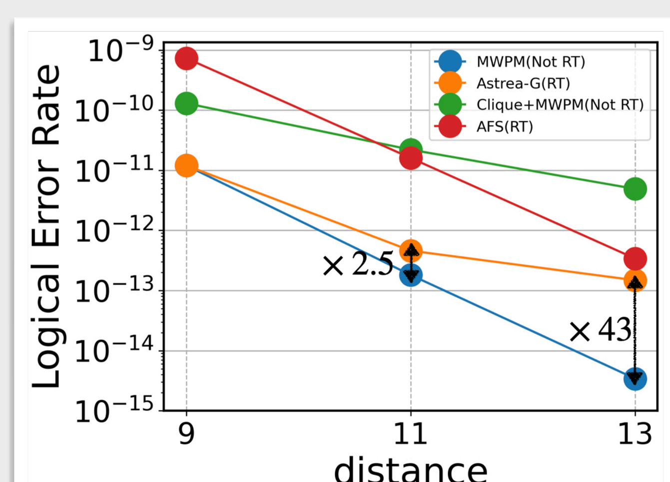


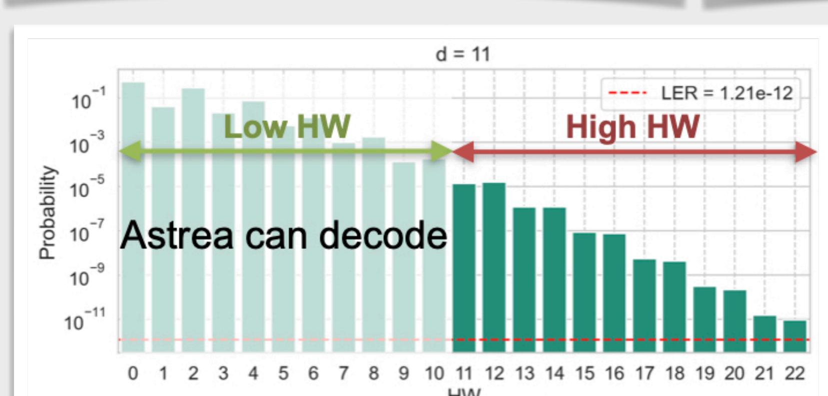
Minimum Weight Perfect Matching (MWPM) is a gold standard for decoding surface codes.

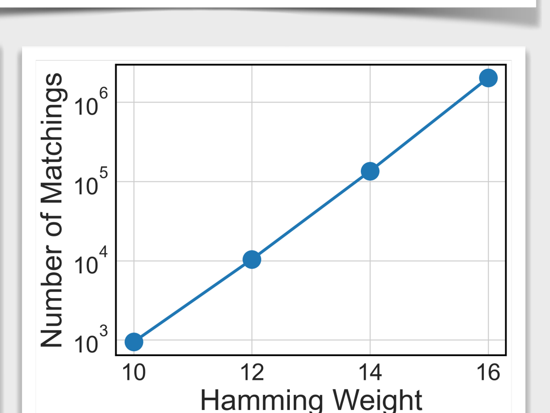
Real-Time MWPM Decoder

- To prevent backlog of errors, we require to decode errors within $1\mu s$.







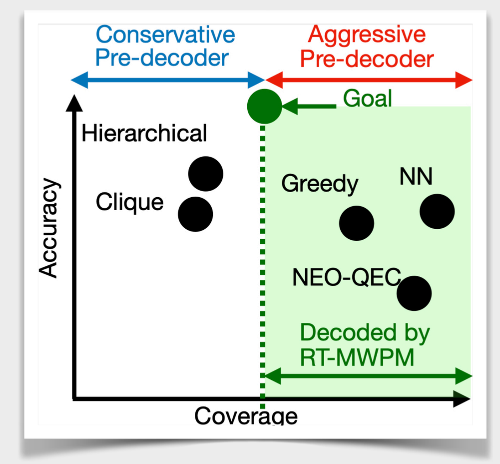


There is a gap between real-time and ideal MWPM for distance more than 9.

PROMATCH: An Efficient Predecoder

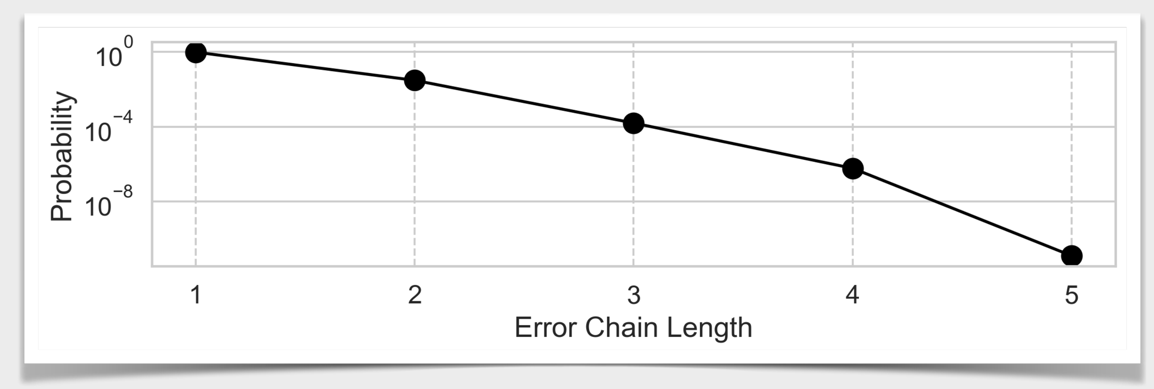
1. **High Accuracy:** Correctly matching the flipped bits, not limiting the accuracy of the main decoder.
2. **Sufficient Coverage:** Covering enough number of flipped bits, making sure that the rest is manageable by the decoder.

We propose **Promatch** that strikes the right balance between accuracy and coverage.

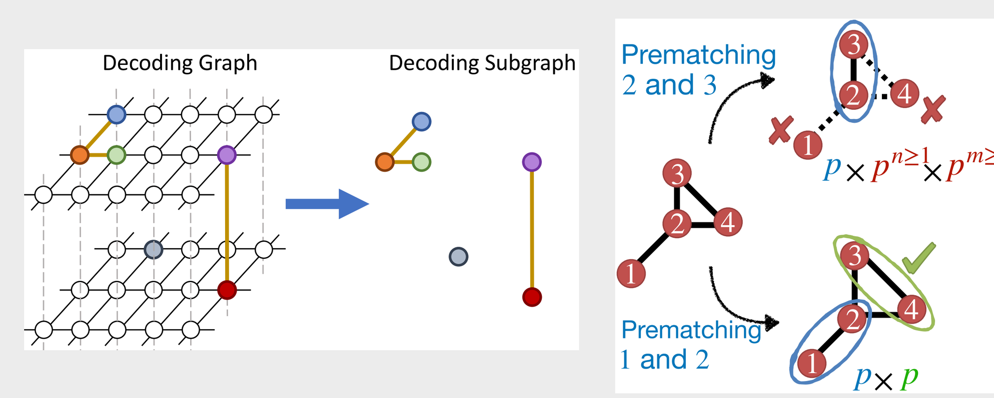


Promatch: An Adaptive Locality-Aware Greedy Predecoder

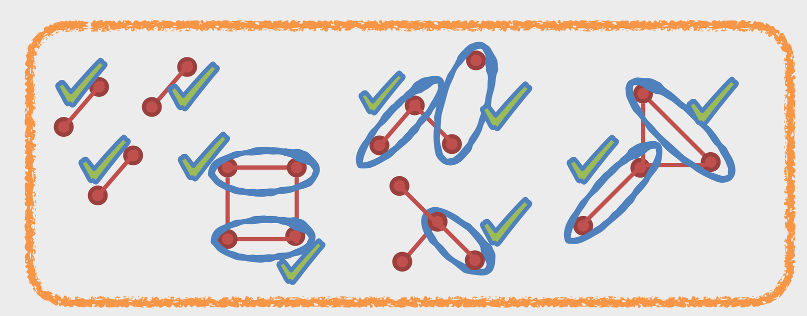
- **Why greedy?** error chains of length 1 are extremely common.



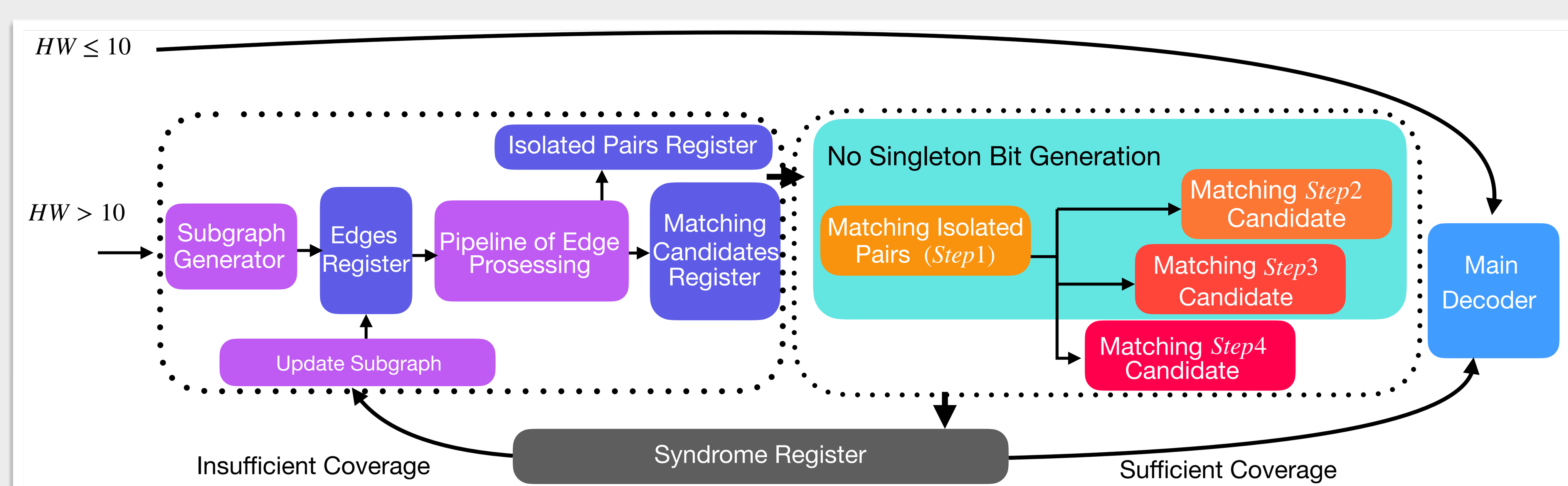
- **Why locality-aware?** *Singletons* are matched along an error chain of length higher than 1, resulting in higher weights in MWPM solution.



- **Why adaptive?** Promatch starts with simple matchings (isolated pairs) and to ensure **sufficient coverage**, it adaptively makes more risky decisions.

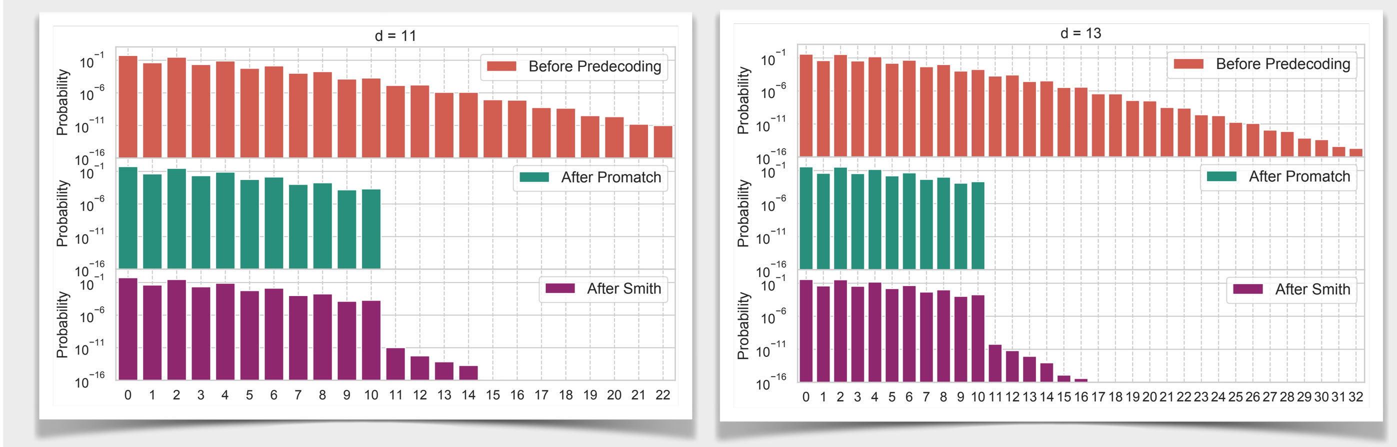


Overview of Promach

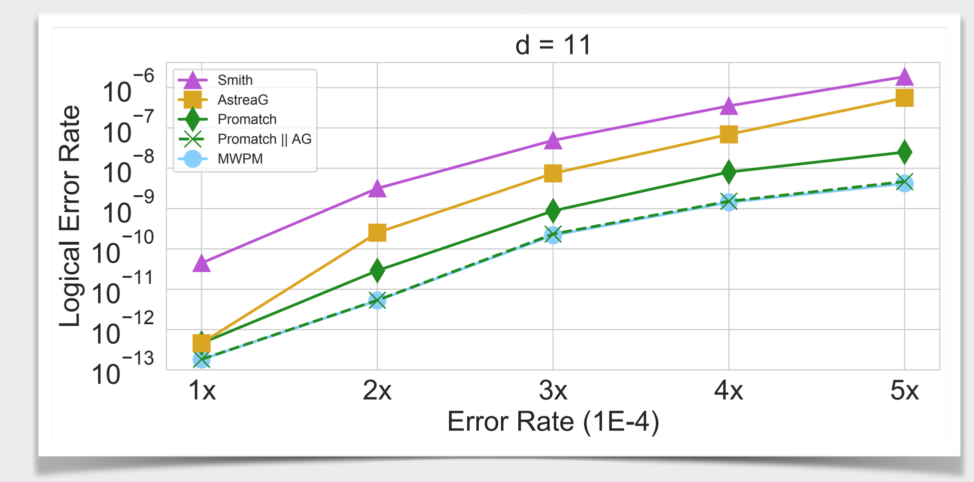


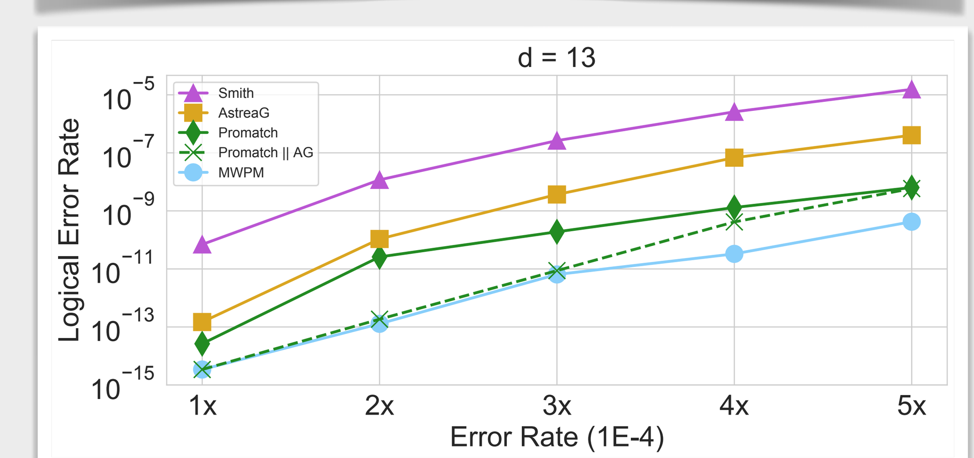
Evaluations

- Promatch always reaches the sufficient coverage and reduces HW to at most 10.



- Promatch outperforms prior works in accurately decoding surface code of distance 11 and 13, and also achieves MWPM logical error rate when it runs in parallel with Astrea-G, for d = 11 (up to $p = 5 \times 10^{-4}$) and d = 13 (up to $p = 3 \times 10^{-4}$).





Conclusion

Promatch extends MWPM decoding to distance 13 by utilizing adaptive predecoding, effectively simplifying high Hamming weight syndromes for faster processing. This approach enhances quantum error correction real-time decoding, especially when combined with Astrea-G, by balancing accuracy and coverage.