# **SUPERCONDUCTOR FINAL REPORT**

Course:

CSC 467/667

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**Introduction**

What is a Superconductor?

A substance known as a superconductor can conduct electricity or move electrons from one atom to another without encountering any resistance. This implies that once the material reaches "critical temperature" (Tc), the temperature at which it turns superconductive, no heat, sound, or other types of energy would be emitted from it.

Superconductivity is a set of physical properties observed in certain materials where electrical resistance vanishes, and magnetic flux fields are expelled from the material. Any material exhibiting these properties is a superconductor. Unlike an ordinary metallic conductor, whose resistance decreases gradually as its temperature is lowered even down to near absolute zero, a superconductor has a characteristic critical temperature below which the resistance drops abruptly to zero. An electric current through a loop of superconducting wire can persist indefinitely with no power source (Wikipedia *Superconductivity*).

**Problem:**

The superconductor can only endure pressures that are comparable to those at Earth's core, which is a serious limitation that prohibits it from being instantly practical. However, researchers are optimistic that it may pave the way for the development of materials with zero resistance that can function at lower pressures. Although superconductors are employed in magnets, their usage is limited because, depending on the material, strong magnetic fields beyond a particular critical threshold may cause a superconductor to regress to its non-superconducting state even when the material is kept well below the temperature range.

Computer parts, motors, generators, transformers, medical magnetic imaging devices, magnetic energy storage systems, and extraordinarily sensitive devices for measuring magnetic fields, voltages, or currents might all be made of superconducting materials. Low power dissipation, quick working speeds, and high sensitivity are the main advantages of superconductor-based electronics.

Why is superconductor useful and why do we need a model that predicts superconductivity?

Superconductors are very useful in many science fields. Of the many uses of superconductors includes Particle Colliders, Magnetic Resonance Imaging (MRI), and Magnetic Levitation for bullet trains (Uses of Superconductors).

However, as stated by Hamidieh, superconductors are “... the absence of any theory-based models.” (2018). And therefore, a prediction model can prove useful for the lack of theory-based models as said above.

**Objectives:**

Create and compare models that can predict the critical temperature of a superconductor. For this project, we utilized our understanding and what we learned in class to experiment the effectiveness of some Machine Learning models.

**Related work done by others:**

Prediction of Critical Temperature of Superconductors using CART Models by Yohanes Nuwara: <https://www.kaggle.com/code/yohanesnuwara/superconductor-prediction-rfr>

We based our project on Yohanes Nuwara’s model. However, the main difference here is that our project is more of an experimental ground for different models. Moreover, for deciding how many attributes to retain, we simply plot all the singular values and decide how large of a value should that we will use it for the models, comparing to Yohanes’s variance ratio method.

The most recent work, which was published in Nature on October 14th, appears to give solid proof of high-temperature conductivity, according to physicist Mikhail Eremets from the Max Planck Institute for Chemistry in Mainz, Germany. He does, however, add that additional "raw data" from the trial would be nice. It confirms a line of inquiry that he started in 2015 when his team announced the development of the first high-pressure, high-temperature superconductor, a hydrogen and sulfur compound with zero resistance up to 70 °C, he says.

A high-pressure combination of hydrogen and lanthanum was shown to be superconductive at 13 °C in 2018. However, the most recent finding, a material composed of carbon, sulfur, and hydrogen, is the first observation of this type of superconductivity in a combination of three elements as opposed to two. The combinations that might be utilized in forthcoming experiments to find new superconductors have been significantly expanded, according to Ashkan Salamat, a scientist at the University of Nevada, Las Vegas. We've opened a whole new zone of investigation, he proclaims. Materials that superconduct at high pressures but not at extremely high pressures can already be used, according to Maddury Somayazulu, a high-pressure materials expert at Argonne National Laboratory in Lemont, Illinois.

The results suggest that you might lower the working pressure of a superconductor by "appropriately choosing the third and fourth element," he says.

Additionally, the study supports prior hypotheses by theoretical physicist Neil Ashcroft of Cornell University in Ithaca, New York, that hydrogen-rich materials may superconduct at temperatures far higher than previously thought.

**Reviews:**

The transition temperature is lowered by the current flow in the superconductor. The transition temperature also decreases with the addition of an external magnetic field. When the magnetic field rises over a certain threshold, different consequences depend on the material. The sudden loss of superconductivity is referred to as a superconductor type.

Chart, histogram

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For Type II superconductors, there are two critical field strengths; at the lower one, the field begins to penetrate, and at the higher one, the superconductivity dissipates. Given that in the space in between, the magnetic field progressively penetrates the conductor in the form of tiny tubes at temperatures, this would undoubtedly have a considerable influence on current technology (about 300 K).

Chart, line chart

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**Methods used in the project:**

For our project, we used and compared 3 models: Linear Regression, Ridge Regression, and Random Forest Regressor. For Linear Regression, we tested the model with and without dimensionality reduction.

**Reducing data dimensionality:**

Because of the large size of the dataset, we implemented Principal Component Analysis (PCA) to run in an acceptable amount of time. To find what attributes are deemed the “principal components”, we first run the whole database through Scikit-learn PCA, then we print out the singular values of each of the 81 components.

Finally, we determine how many components we wanted to keep based on these values, in this case, we used 20 components with the largest eigenvalues to retain most of the information (values that are roughly larger than 80).

A screenshot of a computer

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Chart

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*81 singular values of each of the attributes and its corresponding plot.*

**Result screenshot with the score:**

Chart, scatter chart

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*Linear Regression*

**Models screenshot with PCA:**

Chart, scatter chart

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*Linear Regression*

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*Random Forest Regression*

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*Ridge Regression (alpha = 200)*

**GitHub code link and discussion**

Link: <https://github.com/CSC467/CSC467-Final-Project.git>

<https://github.com/CSC467>

We started out discussing what we wanted to achieve for this project. I wanted to make a simple prediction model that is easy to understand, perhaps even for people who are new to Machine Learning.

So, using was known what we learned during the course and during our private study time. We first planned to just make one model while learning how to manipulate data frames and implement the codes. But after seeing what our peers have done, we decided that our code was inadequate. We decided to expand further, by implementing more methods and applying them in models for testing and model comparison.

**Summary, Limitations, and Conclusion**

The development of ultra-strong magnetic fields for high-resolution MRI and nuclear magnetic resonance (NMR) systems, as well as future advanced high-energy physics, are all made possible using superconducting materials. These materials have the potential to significantly advance high-field magnet technology, enabling high-efficiency electric power generation, high-capacity lossless electric power transmission, small, lightweight electrical equipment, high-speed magnetic levitation transportation, and small, lightweight electrical equipment.

The efficiency, economy, and operating conditions (temperatures and magnetic fields) of these applications are significantly influenced by the electromagnetic and mechanical properties of superconductors, as well as by the prices of their manufacturing and materials. This viewpoint tackles essential characteristics crucial to practical applications and significant issues, and it emphasizes the challenges they encounter and their current position in practical applications to create wire for practical superconducting materials. Finally, perspectives on the future are taken into account for their potential and advancement in the uses of magnetic and superconducting technologies.

There are quite a few human limitations factors for this project. We only used what we understood in class and through our research while working on the project. As such, this project might be considered a bit simple, however, that isn’t to say we learned quite a lot about Machine Learning, and one of our models works rather adequately for the task at hand.

In conclusion, using the whole dataset gives better results for linear regression. Linear regression utilizing PCA did a bit worse - it seems more sensitive to the loss of data. However, RFR cannot run in a reasonable amount of time without PCA, we do not have the result because we gave up after waiting for over 30 minutes. With PCA, the run time for the RFR model is less than 1 minute, with a rather decent score.

Ridge Regression did the worst because the model doesn't need regularization. Any attempt to increase regularization strength made it worse, therefore is rather redundant. Perhaps one of the main reasons is that there is sufficient data.

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*Overall score of all the models*

**References**

Uses of Superconductors. Superconductivity. (n.d.). Retrieved November 29, 2022, from http://www.chm.bris.ac.uk/webprojects2000/igrant/uses.html “Uses of Superconductors.”

Hamidieh, K. (2018, August 10). A data-driven statistical model for predicting the critical temperature of a superconductor. Computational Materials Science. Retrieved November 29, 2022, from <https://www.sciencedirect.com/science/article/abs/pii/S0927025618304877?via%3Dihub>

Wikimedia Foundation. (2022, November 29). Superconductivity. Wikipedia. Retrieved November 29, 2022, from <https://en.wikipedia.org/wiki/Superconductivity>

Link 2 Source Code: <https://github.com/CSC467/CSC467-Final-Project.git>

(For Report) <https://github.com/CSC467>