# How Configurable is the Linux Kernel? Analyzing Two Decades of Feature-Model History – Summary

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**Abstract:** This work was accepted for publication in the *ACM Transactions on Software Engineering and Methodology* (TOSEM) in 2025 [Ku25a].

The Linux kernel is a well-known configurable software system, which can be adapted to a wide range of hardware platforms and use cases. Despite its importance, fundamental aspects of the kernel's configurability (such as its number and evolution of features and configurations) remain poorly understood, largely due to the kernel's size and the limited scalability of existing analysis techniques. This work provides the first comprehensive, longitudinal study of the Linux kernel's configurability, covering more than two decades of feature-model history. Using our analysis tool TORTE, we extract, transform, and analyze over 3,000 feature-model versions to quantify and characterize the kernel's variability over time. Our study establishes a foundation for reproducible configurability analyses and contributes data, insights, and recommendations that support both researchers and practitioners in understanding and managing variability in the Linux kernel.

**Keywords:** Linux Kernel, Feature Modeling, Software Product Lines, Software Variability

Today, the operating system Linux is widely used in diverse environments, as its kernel can be configured flexibly. In many configurable systems, managing such variability can be facilitated in all development phases with product-line analyses. These analyses often require knowledge about the system's features and their dependencies, which are documented in a feature model. Despite their potential, product-line analyses are rarely applied to the Linux kernel in practice, as the Linux kernel's feature model continues to pose challenges for scalable and accurate analysis. Unfortunately, these challenges also severely limit our knowledge about two fundamental metrics of the kernel's configurability, namely its number of features and configurations. We identify four key limitations in the literature related to the scalability, accuracy, and influence factors of these metrics, and, by extension, other product-line analyses: (1) Analysis results for the Linux kernel are not comparable, because relevant information is not reported; (2) there is no consensus on how to define features in Linux, which leads to flawed analysis results; (3) only few versions of the Linux kernel have ever been analyzed, none of which are recent; and (4) the kernel is perceived as complex, although we lack empirical evidence that supports this claim.

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We address these limitations with a comprehensive, empirical study of the Linux kernel's configurability, which spans its feature model's entire history from 2002 to 2024 [Ku25a]. We address the above limitations as follows: (1) We characterize parameters that are relevant when reporting analysis results; (2) we propose and evaluate a novel definition of features in Linux as a standardization effort; (3) we contribute TORTE, a tool that analyzes arbitrary versions of the Linux kernel's feature model; and (4) we investigate the current and possible future configurability of the kernel on more than 3,000 feature-model versions.

Based on our results, we highlight eleven major insights into the Linux kernel's configurability and make seven actionable recommendations for researchers and practitioners. Regarding insights, we found that the Linux kernel grows more complex and configurable, with $\approx 840$ new features and $\approx 10^{60} - 10^{146}$ times more configurations per year. Indeed, today's kernel is likely the largest known product line in terms of configurability, with $\approx$ 20,000 features and $\approx 10^{1,600} - 10^{3,600}$ configurations in total. Furthermore, we even expect the number of features to approximately double in twenty years. Regarding recommendations, we want to encourage researchers to report relevant parameters when analyzing the Linux kernel, to accurately count its features, and to identify and push the limits of computationally complex analyses on the kernel. We also encourage practitioners to use configurability metrics when making development decisions, and to reduce variability where possible. Thus, we aim to foster a joint effort by practitioners and researchers to improve the scalability and accuracy of product-line analyses on the Linux kernel in the long term.

**Data Availability** In our accompanying *Replicated Computational Results (RCR)* report [Ku25b], we bundle all data relevant to our evaluation for the purpose of reproducibility and long-term archival. This includes the feature-model extraction tool TORTE, as well as a comprehensive feature-model dataset and experimental results.[4]

## References


[Ku25a] Kuiter, E.; Sundermann, C.; Thüm, T.; Heß, T.; Krieter, S.; Saake, G.: How Configurable is the Linux Kernel? Analyzing Two Decades of Feature-Model History. Trans. on Software Engineering and Methodology (TOSEM), To appear, 2025, DOI: 10.1145/3729423.

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[4] https://zenodo.org/doi/10.5281/zenodo.8190055