High-Performance Integral Transforms for the Next Generation of Astrophysical Codes

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As a new generation of astronomical surveys takes the stage and promises to capture data on an unmatched number of astrophysical sources, our community is in dire need of high-performance simulations and data analysis tools. In this context, a significant rewrite of some of the key codes in the computational astrophysics software stack is currently taking place, including the development of Dyablo for example. In our case, and to explore how the algorithms we all depend upon can take advantage of the latest advances in programming languages, we decided to focus our efforts on a critical component of the software stack: integral transforms. From FFTs to Hankel and including Laplace transforms, many of our high-performance codes rely on them, sometimes through third-party libraries such as FFTW. In this presentation, we will open what may sometimes be considered as a black box, to see how modern programming approaches allow for combining genericity, expressivity, and performance, leading to simple code that is able to compete with traditional approaches. We will illustrate, in particular, how FFTs can be revisited using the current C++ standards to combine several layers of parallelism, from bit-level parallelization to distributed computing, and including SIMD optimizations. We will detail how high-levels of optimization can be combined with generic interfaces, making integral transforms far easier to use. Finally, we will demonstrate the use of our library on concrete astrophysical use cases, including a modern version of initial condition generation for cosmological simulations. Overall, this presentation will provide a perfect platform to illustrate advanced programming approaches that can benefit modern astrophysics codes far beyond the sole scope of integral transforms.