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Seismic signal processing on heterogeneous supercomputers

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The processing of seismic signals – including the correlation of massive ambient noise data sets – represents an important part of a wide range of seismological applications. It is characterized by large data volumes as well as high computational input/output intensity. Development of efficient approaches towards seismic signal processing on emerging high performance computing systems is therefore essential. Heterogeneous supercomputing systems introduced in the recent years provide numerous computing nodes interconnected via high throughput networks, every node containing a mix of processing elements of different architectures, like several sequential processor cores and one or a few graphical processing units (GPU) serving as accelerators. A typical representative of such computing systems is “Piz Daint”, a supercomputer of the Cray XC 30 family operated by the Swiss National Supercomputing Center (CSCS), which we used in this research. Heterogeneous supercomputers provide an opportunity for manifold application performance increase and are more energy-efficient, however they have much higher hardware complexity and are therefore much more difficult to program. The programming effort may be substantially reduced by the introduction of modular libraries of software components that can be reused for a wide class of seismology applications. The ultimate goal of this research is design of a prototype for such library suitable for implementing various seismic signal processing applications on heterogeneous systems.

As a representative use case we have chosen an ambient noise correlation application. Ambient noise interferometry has developed into one of the most powerful tools to image and monitor the Earth’s interior. Future applications will require the extraction of increasingly small details from noise recordings. To meet this demand, more advanced correlation techniques combined with very large data volumes are needed. This poses new computational problems that require dedicated HPC solutions. The chosen application is using a wide range of common signal processing methods, which include various IIR filter designs, amplitude and phase correlation, computing the analytic signal, and discrete Fourier transforms. Furthermore, various processing methods specific for seismology, like rotation of seismic traces, are used. Efficient implementation of all these methods on the GPU-accelerated systems represents several challenges. In particular, it requires a careful distribution of work between the sequential processors and accelerators. Furthermore, since the application is designed to process very large volumes of data, special attention had to be paid to the efficient use of the available memory and networking hardware resources in order to reduce intensity of data input and output.
In our contribution we will explain the software architecture as well as principal engineering decisions used to address these challenges. We will also describe the programming model based on C++ and CUDA that we used to develop the software. Finally, we will demonstrate performance improvements achieved by using the heterogeneous computing architecture.

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