A FRAMEWORK FOR DESIGNING CONTEXT-AWARE ADAPTIVE EMBEDDED SYSTEMS

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Abstract

This thesis considers many different aspects of modern embedded systems which together make the process for designing such systems significantly complex. Firstly, due to their recent success, machine learning, natural language processing, and computer vision techniques are increasingly becoming an integral part of embedded systems. A key characteristic of algorithms in these domains is that they are not “perfect” - the results generated have a certain accuracy and thus implicitly a certain error rate. The same task may be implemented with many choices which differ in accuracy and computation efforts and hence provide a few trade-off options to system designers. Secondly, today's platforms provide multiple compute fabrics ranging from CPU, GPU, FPGA to customised accelerators in the same device. The presence of multiple fabrics very often increases options for execution of application tasks and therefore, provides additional flexibility but again with trade-off among parameters like performance, energy consumption, etc. Thirdly, the systems need to adapt the operating task modes in response to changes in various factors that are external to the system. We refer to these factors together as *context*. We call systems that are being designed to address the above three aspects of complexity as *Context-aware Adaptive Embedded Systems (CAES)*.

Consider early stages of designing such systems when even platform definition is still to be decided. The system designer needs to evaluate various options of task modes implemented along with the possible choices for platform components and the range of context in which the device is expected to operate. Clearly, there is a need for joint consideration of platforms, tasks, and context at this stage to reach good solutions which results in many-fold increase in the possible space of implementation choices. Addressing such complexity through *Design Space Exploration (DSE)* in a structured manner is a key contribution of this thesis and forms the first step of the proposed two-step process for designing efficient CAES. In this step, a constraint based formulation of the DSE problem along with an iterative pruning approach is used to explore the design space. Various enhancements like quantization, genetic algorithm, and clustering are also integrated into the flow. Further, the DSE step uses a system model as an input, for which a *graphical representation* is proposed in the thesis. This representation is capable of capturing different choices of different task modes and components as well as the

effect of context. Various rules are defined to automatically translate this representation into constructs from constraint logic programming (CLP) to enable its direct use in DSE.

The second step of the proposed CAES design process uses the reports generated from the DSE step to automatically identify suitable mapping of various contexts to task modes (called *run-time controller specification*), corresponding to the platform chosen during the DSE step. The flow uses concepts from multi-valued logic (MVL) minimization to further minimize the generated run-time controller specification in order to reduce the total number of mappings. Such minimization process also provides insights into the operation of the system which can be useful for further refinements in the implementation.

Three different real systems have been used as case studies to demonstrate the applicability of the proposed design process. These case studies are diverse in their end-application, in the nature of the platforms and task modes, and in the metrics and context that are relevant for these systems. For all the three systems, many new design options become feasible due to consideration of components, task modes, and context together. The thesis presents such design options as well as associated trade-offs identified using the proposed framework.

Overall, this thesis defines a new class of systems named CAES and presents a comprehensive design methodology for such systems which can be used from a very early stage in the design process.