



Research paper

Designing and implementing a multi-core capable integrated urban drainage modelling Toolkit: Lessons from CityDrain3



Gregor Burger^a, Peter M. Bach^{b,c}, Christian Urich^{a,1}, Günther Leonhardt^{a,2},
Manfred Kleidorfer^{a,*}, Wolfgang Rauch^a

^a Unit of Environmental Engineering, University of Innsbruck, Technikerstrasse 13, Innsbruck 6020 Tirol, Austria

^b Monash Infrastructure Research Institute, Department of Civil Engineering, Monash University, Clayton 3800 VIC, Australia

^c Cooperative Research Centre (CRC) for Water Sensitive Cities, Monash University, Clayton 3800 VIC, Australia

ARTICLE INFO

Article history:

Received 16 March 2016

Revised 28 July 2016

Accepted 4 August 2016

Keywords:

Integrated urban drainage

Modelling

Simulation framework

Object-oriented design

Multi-core

Parallel computing

ABSTRACT

Integrated urban drainage modelling combines different aspects of the urban water system into a common framework. With increasing pressures of a changing climate, urban growth and economic constraints, the need for wider spread integration is necessary in the interest of a sustainable future. Greater complexity results in greater computational burden but modelling packages will, likewise, need to be flexible enough to allow incorporation of new algorithms. With advancements in modern information technology, a parallel implementation of such a modelling toolkit is mandatory while still leaving its users the flexibility of extensions. The design and implementation of the integrated modelling framework CityDrain3 shows that it is possible to write research code that is high-performance and extensible by many research projects. Three use case scenarios are presented to showcase the application of CityDrain3. The performance advantage of parallelization (up to 40 times compared to its predecessor) and the scalability of the framework are also demonstrated.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

The concept of integration in urban drainage systems was first discussed several decades ago and has received generous attention ever since [6,7,42,48,54]. With increasing pressures of a changing climate, urban and population growth and economic constraints the need for wider spread integration has been regarded as necessary in the interest of an ecologically sustainable future [9,51,55,56]. This push for system-wide management has been encouraged internationally and is reflected in legislation such as the Water Framework Directive in Europe [24] and the National Water Quality Management Strategy in Australia [3].

Numerous simulation tools, often promoted as decision-support tools, integrated modelling packages or numerical laboratories already exist for modelling different urban environments (i.e. water, energy, air, soil, etc.). Within the water sector, drainage models such as WEST [74], SIMBA [31] or the MIKE suite [17] have

been applied to case studies involving the interactions between catchment, drainage system (combined and separate), treatment plant and downstream environments (e.g. [23,45,57,63]). Apart from drainage, integrated modelling has also found value in other areas of the urban water sector. Models such as MUSIC [25], Aquacycle [49], UVQ [47] and UrbanDeveloper [26] have transferred integrated modelling concepts to problems with greater complexity and broader scope. Especially the integration of urban drainage systems into the evolution of the urban environment is on increasing interest [39,46,62,66,73,76]. It is reasonable to assume that, with increasing environmental management objectives, system boundary and scope will grow [6,37,44]. This has two implications for modelling. Firstly, greater complexity results in greater computational burden [13]. Secondly, modelling packages will need to be flexible enough to allow incorporation of new and/or revised algorithms. The second issue was emphasised by Rauch et al. [54] at the second INTERURBA conference, calling for a more unified and cooperative model development approach and was later reflected, for example, in the HarmonIT project with OpenMI as its flagship tool [28].

CITY DRAIN II [1] was developed almost a decade ago to solve shortcomings in integrated urban drainage modelling (IUDM). The model allows lumped, conceptual simulations of urban drainage systems and was built in the MATLAB/Simulink environment as

* Corresponding author. Fax.: +43 512 507 62199.

E-mail address: manfred.kleidorfer@uibk.ac.at (M. Kleidorfer).

¹ Present address: CRC for Water Sensitive Cities, MONASH Water for Liveability, Department of Civil Engineering, 23 College Walk, Monash University Clayton 3800 VIC, Australia

² Present address: Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology, 971 87 Luleå, Sweden

several other models of its time (e.g. SIMBA). Although CITY DRAIN II has been adopted in many case studies across the world (see e.g. [18,59,75]), its shortcomings have to be recognised in light of current needs. The software's design falters at computationally intensive simulations. The framework is not flexible enough to allow efficient interfacing with other models (e.g. simulation files cannot be easily generated with code). The user experience in extending the software with user-defined modules has been found challenging, especially for elementary programmers. Although widespread, a MATLAB/Simulink license may also not always be available to the user.

In light of these issues, major developments undertaken have resulted in a new form of this model. CityDrain3 addresses the shortcomings of CITY DRAIN II as well as the needs for a more flexible modelling development environment that has been advocated in the literature. The model also utilises the potential of multi-core technology as was demonstrated in a parallel-computing case study [12]. CityDrain3 is coded in C++ with a simple Python scripting option for less experienced programmers/engineers, thereby making it a standalone program that can be installed on any computer with any operating system. These upgrades have not only sped up computation of existing urban drainage models, but have also provided additional opportunities to the modeller including (but not limited to): 1) implementation of physically-based models (often requiring iterative solutions, which greatly impede computational efficiency), 2) rigorous model calibration (multi-objective optimisation or model parameter identifiability analysis), 3) sensitivity or uncertainty analysis and 4) faster real-time control and data management. Most of all, CityDrain3 has evolved its predecessor to a more generic modelling environment for continuous simulation of mass quantities and fluxes through any kinds of network systems. The software design enables CityDrain3 to act as a common platform for integrating model algorithms with each other, or as a component of larger and more complex software packages.

The present paper aims to describe the design and implementation of this novel modelling environment, CityDrain3, particularly: its unique features, software design and extensibility that have resulted in valuable lessons about integrated model development from a computer science and model performance perspective. These are accompanied by several application examples of the framework discussed thereafter. These range from parallel computing of urban drainage networks and model identifiability analysis to real-time control and a planning study for decentralised urban water management. The focus here will nevertheless remain in the urban water sector.

2. Background

2.1. Integrated urban drainage modelling

A model is a schematic (mathematical) description of physical occurrences and always a simplification of reality neglecting certain known and unknown processes. Model results can only be an estimation of real occurrences. Quality and accuracy of that estimation depends on the quality of the input-data, model structure and model parameters, which have to be determined from reality by observation and/or calibration. Since the 1970s and 1980s, when the first computer models for simulating urban drainage systems were introduced, steady progress in the development of more sophisticated approaches for water infrastructure planning, evaluation and operation has been observed [6,54]. Today, urban drainage simulation models are state-of-the-art instruments for planners, consultants and scientists working in the field of urban hydrology and water management. Numerous commercial, freeware and open-source software products are readily available. Applications

of urban drainage models are far-ranging encompassing design, optimization and evaluation of pipe networks, stormwater treatment facilities, combined sewer overflows and real time control strategies. They either provide data for other simulation models as wastewater treatment plant simulation or river quality models or even include those aspects in the model environment. Furthermore, models are increasingly used for exploring possible future scenarios (e.g. impact of climate change or urbanization as shown, for example, by [2,15,46,64,70,71]).

With increasing complexity of models, data requirements for model building and model calibration become more challenging. Hence, it becomes more difficult to analyse model structure taking into account the relevance of input and calibration data uncertainties [16]. Today the accuracy of urban drainage model outputs with regard to model uncertainties is questioned and uncertainty estimation procedures are required [20–22,34]. Additionally, integration of urban drainage models with models assessing urban development and climate change leads to an increasing computational demand and subsequently to the need for implementing new solutions in the software environment.

2.2. Parallel computing

At the same time as developments in urban drainage modelling, parallel computing (PC) has also advanced. PC is a computer science discipline that deals with algorithms and applications that run in parts, or even as a whole, in parallel. The main reason for introducing complexity in software project in the form of parallel computing is the need for increased performance [14]. In fact, the stagnation in single thread performance of consumer processors (about a decade ago) led to the advent of multi-core processors [19,50]. The general availability of consumer range processors, capable of running applications in parallel, resulted in a fundamental shift towards concurrency in software. Sutter [68] states that “the free lunch is over” — i.e. the assumption of software becoming faster as hardware speed increases — is no longer valid. This is because chip vendors are facing physical limits of the hardware materials that prevent them from further scaling processing clock rates. The adopted solution instead was to scale the number of transistors, which are shared among several cores, instead of clock rates.

This transition of software towards concurrency changed the design of applications. Complexity has further increased with the introduction of general purpose graphical processing units (GPGPU) computing [43] where programmers need to cope with many thousand parallel processing units. However, parallel computing has to cope with a lot of issues that arise by coordinating multiple tasks running in parallel [27]. Andrew Richards of Codeplay Software states that: “Optimizing code for multi-core is a tough task rewarded by elation and frustration, and it is hard to predict which you will experience when” [58]. In the future, we might see a very heterogeneous landscape of parallel computing devices, each one suited for different computational requirements adding additional complexity to software development [69].

Parallel computing is a complex undertaking and requires novel skill sets for programming high performance application on modern hardware. However, it needs to be implemented in modern software in order to exploit the available, but currently untapped, computing resources provided by modern CPUs. To harness the benefits of parallel computing, CityDrain3 was designed to be multi-core capable.

3. Development approach

CityDrain3 is an integrated modelling environment for scientists and practitioners. This leads to conflicting design criteria (e.g. com-

Download English Version:

<https://daneshyari.com/en/article/567082>

Download Persian Version:

<https://daneshyari.com/article/567082>

[Daneshyari.com](https://daneshyari.com)