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論　文　題　目	Advanced Development Methods for Information Communication Software Guaranteeing High Performance （高性能情報通信ソフトウェアのための高度開発手法の研究）
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論 文 内 容 要 旨

Effective and innovative software development methods for high-performance reliable information communication systems are established to meet the needs of a diverse range of telecommunication users and to provide easily and efficiently various services and capabilities necessary for the multimedia and e-life age. In particular, analysis is performed from the standpoints of quick service development and deployment, high reliability of system operation, and extensibility to multimedia service development as well as high performance. Mechanisms to realise these requirements are proposed, evaluated, and systematised.

Specifically, the following items are studied.

• Establishment of advanced software development methods that can solve problems in developing existing communication systems, and promote the introduction of multimedia services. The methods must handle information communication processing for telephone/ISDN switching, ATM, frame relay, and advanced intelligent networks as well as multimedia communications.

• Software modelling to achieve excellent software development productivity and maintainability under strict performance and reliability conditions.

• Establishment of a high-performance information communication software architecture to handle a large amount of traffic.

• Quick service provisioning by updating the online software providing services.

• Advanced software development support to enhance software development productivity and maintainability.

• An extensible information communication platform to quickly provide new multimedia services, such as voice/data integration, the next-generation mobile communications, or content delivery.

• Systematisation of information communication software development methods to be applied for introducing new multimedia services easily as well as for maintaining existing information communication software.

To proceed with the study of these items, i.e., the establishment of information communication software development methods that realise realtime, highly multiple processing along with excellent productivity and reliability, the following issues are considered.

• The software development methods must be used to manage a huge amount of developed software. The software architecture must support ten years or more of development by accommodating hardware upgrades, and must be easy to understand so that new generations of software developers will be able to carry on easily.

• The software to be designed must meet the conditions of realtime and highly multiple processing at a level about 100 times greater than that of ordinary information processing systems.

• The same architecture must be scalable across a range of systems from small to very-large capacity.

• It must be possible to modify or add programs in the online file without affecting running services. The online file updating method must be applicable not only to bug fixes but also to the addition of new service functions.

• It must reduce human effort in software development, i.e., designing, coding, debugging, and managing the development process. Automation or machine support should be introduced for such purposes.

• It must be possible to achieve efficient handling of voice-data integration and to provide various new multimedia services readily. At the same time, traffic efficiency must be achieved.

Considering the above points, each Chapter discusses the study items in the following way.

Chapter 1 shows the motivations for this thesis. The research backgrounds and existing problems are analysed and the research objectives are presented.

Chapter 2 proposes information communication software development methods featuring excellent productivity and highly multiple realtime processing as well as high reliability. Considering the severe conditions for performance, reliability, and development-cost, we

propose a layered software structure, object-oriented programming model, distributed processing mechanisms with location transparency, online file modification processing mechanisms, automated coding mechanisms for routine processing programs, advanced software development supporting, and voice-data integration mechanisms, as the most important key elements for information communication software development methods.

Chapter 3 discusses specific and detailed techniques for the above software development methods. We show hierarchical object-oriented software implementation techniques featuring high productivity. Also, we consider how to minimize the number of dynamic program steps, effectively map objects onto the execution unit of the realtime OS, save calls in service at the time of system failure, and reduce the time taken for restarting. Then, to apply the system to areas with a high traffic density, we establish and evaluate multiprocessor distributed object-oriented processing mechanisms. Its main part, i.e., the inter-object communication mechanism (called the object request broker) uses CORBA-like concepts, but to attain sufficient performance for use in information communication systems, various approaches are devised. The proposed mechanisms guarantee good performance and have the potential to be the foundation for developing future information communication software.

Chapter 4 discusses extended techniques for easy and effective development of multimedia service software. We present software development and file updating methods with an eye to adding new services, in particular, techniques for modifying the executing files during online operation without affecting services being provided, and evaluate their effectiveness. Advanced software development support techniques for improving software productivity and ease of maintenance are established and evaluated. The main approach is tool-based automated coding with special care for realtime and reliable processing compared with the approaches used in actual commercial software systems. A large amount of routine processing in information communication systems is automatically coded. For new multimedia service provision, we show key techniques for integrating voice and data traffic in a single structure. Studies on voice and telephony over ATM (VTOA) networking are discussed. It is clarified that this will be the basis for constructing multimedia-oriented information communication services.

Based on the above discussion, Chapter 5 systematises the design methods for multimedia-oriented information communication software featuring good software productivity, ease of functional addition, realtime highly parallel processing, high reliability, and extensibility. Case studies show the potential for applying our information communication software development methods to constructing next-generation network software and the next-generation mobile (IMT-2000) service software. Even though it does not require much effort, the extension is deemed to be smoothly achieved.

As total design guidelines for the high-performance reliable information communication software, we first introduce a software architecture divided into four layers - BOS, EOS, application-dependent resources, and application services - in order to hide the hardware architecture, enable software sharing (portability), and separate technical specialisation fields. The lower two layers are dealt with as a common platform, and software is coded based on an object-oriented design. Taking advantage of the object-oriented programming capabilities of the C++ language, a model is devised considering software structural clarity, portability,

measures to prevent performance loss, and software-parts management. For application to large-capacity services, a multiprocessor distributed object-oriented processing mechanism is established taking into account location transparency and the need for high performance. To achieve safe software updating (for bug fixes and service function addition), online plug-in technology is established and used. Change of functions, addition of functions and data, and initialisation processing provide reliable executing-file modification in conjunction with a rollback (plug-out) capability by which faulty programs can be removed automatically. To improve software productivity and maintainability, advanced software development support tools are introduced and used, including mechanisms for automated coding of routine processing programs. Based on these technologies, a software foundation is established for the voice-data integrated processing required for new multimedia services. At the same time, good effects on transmission efficiency are achieved. These techniques are positioned as effective and innovative software development methods for constructing high-performance information communication systems.

In summary, our proposals for software development methods offer the following benefits in providing multimedia-oriented information communication network services with outstanding performance, productivity, reliability, and extensibility.

First of all, the proposed software development methods achieve high software development productivity, about 15% higher than the previously developed communication system. This is mainly due to advanced software development support, such as automated code generation, object-oriented software parts management, development tools, and porting of the common software platform. Also, the well structured layered software architecture contributes to the good software development productivity. Specifically, the automated coding mechanism enables many routine processing parts in information-communication systems, such as office data handling and command/message handling, to be automatically coded (nearly 30% of the total software size). This approach can reduce software development effort by about 10%.

Moreover, the above object-oriented design can be expanded to a multiprocessor environment, leading to a lightweight distributed object communication mechanism with location transparency. This can be applied to a large-scale information communication system handling a large amount of traffic.

In addition, the online plug-in technology enables software upgrading without affecting running services. Field data indicate that this method is almost 100% applicable to bug handling and can be used for many kinds of service addition. In particular, the plug-in initialisation capability has good effects for cases that require special data value setting, registration with other programs, or hardware initialisation before linkage. To widen its applicability more, an enhanced mechanism is also proposed considering complicated task behaviour in the course of call/service processing.

A VTOA-based voice/data integrated processing foundation is established on which future multimedia services can be realised. Two approaches are shown, one based on ATM and the other based on STM, and detailed system/software architectures are proposed. Evaluations

show that the former approach is more effective because it can concentrate traffic at internode sections while the STM-based one can provide the voice-data integration capability more quickly due to its simpler configuration. Also, it is shown that integrated voice-data handling software is implementable with only small changes to the software architecture so far proposed and can be a key to establishing the information communication software development methods.

Finally, our proposed software developing methods are readily applicable to coming-generation network services including the IMT-2000 services. The voice-data integration mechanisms and information communication software foundation mentioned so far are the keys to the construction of such new network services or capabilities.

Future work will include lower-cost development using third-party applications and extension to the ubiquitous communication.

Our advanced software development methods are very effective for in-house development, but for more cost reduction, the use of third-party applications is more important. Based on activities of de facto standardisation communities such as JAIN ™ (Java APIs for Integrated Networks), specifying Java-based portable application program interfaces (APIs), an enhanced platform will be necessary. Because ordinary Java runtime environments are insufficient for the very strict performance requirements needed by information communication systems, studies of a high-performance Java runtime environment as well as efficient and portable APIs for various multimedia services should be done.

It is also important to establish core software technologies for ubiquitous services, which will be realised in the near future. One of the most important aspects of the ubiquitous communication is service composition, where in response to a user's requests a useful and effective network service is automatically constructed in an ad hoc manner from elemental functions that the user has. Our software development methods should be extended to cover this field, particularly for automated service creation.

Overall, the proposed software development methods in conjunction with future extensions will be an indispensable social foundation for the multimedia and e-life age.

Key words
Software development, software architecture, object-oriented programming, software parts, distributed object-orient architecture, plug-in, automated program generation, VTOA (voice and telephony over ATM), multimedia communication

<center>論 文 審 査 の 結 果 の 要 旨</center>

　マルチメディア時代における多様な通信機能の実現には，情報通信ソフトウェアを効率的に作成し，運用システムに迅速に導入できる開発手法の確立が重要となっている．しかし，従来の開発においては，性能確保が最重要視され，ソフトウェアの拡張性や生産性の向上に対する方策は二次的な問題として捉えられ，部分的にしか確立されていなかった．また，マルチメディアサービスに対応する技術基盤も不十分であった．そこで著者は，プログラムの作成支援やオンラインプログラム変更，音声・データ融合方式に着目し，情報通信ソフトウェア開発を高度化する手法に関する詳細な研究を行った．本論文はその成果をまとめたものであり，全編6章からなる．

　第1章は序論である．

　第2章では，性能と信頼性に厳しい情報通信サービスの効率的な提供を目標に，高いソフトウェア生産性とサービス展開性・拡張性を持つ情報通信ソフトウェアを開発するための手法を考案している．ソフトウェア構造化，プログラム作成・導入支援，マルチメディア対応音声・データ融合などの観点に対応する具体的な開発モデルを構成し提案している．これらは，マルチメディアサービスを含めた新しい機能を実現する情報通信ソフトウェアを効率的に開発していく上で重要な成果である．

　第3章では，2章で提案したソフトウェア構造化について，特に，情報通信ソフトウェアのトラフィック処理性能の向上を狙い，マルチプロセッサ制御機構とその配備法を提案している．実システムへの適用を通した性能面，コスト面の評価により，提案手法の有効性を示している．

　第4章では，プログラム作成の支援法と作成したプログラムを運用中のシステムにサービス無中断で導入する機構，及びデータと音声を効率的に重畳する機構とその配備法を提案し，これらが生産性の向上，トラフィック量の低減などの点で有効であることを示している．これは，今後のマルチメディアサービスを効率的に実現するに当たって実用上有用な成果である．

　第5章では，3章と4章で提案したソフトウェア開発手法を体系化している．実際の全国規模ネットワークに導入した際に得られたデータを用いた評価により，提案の開発手法が総合的に生産性の向上に有効であることを示している．これは，今後の情報通信ネットワークを発展させて行く上で重要な成果である．

　第6章は結論である．

　以上要するに本論文は，情報通信ネットワークのソフトウェア開発において，高性能高信頼という要求条件を満たしつつ，ソフトウェア開発効率を向上させる手法に関する研究を行い，情報通信ネットワークのソフトウェア開発手法に関する有用な知見を与えたものであり，情報基礎科学の発展に寄与するところが少なくない．

　よって，本論文は博士（情報科学）の学位論文として合格と認める．