UDK 004.382.7

OSNOVE 64-BITNOGA RAČUNALSTVA
THE BASICS OF 64-BIT COMPUTING

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***Sažetak**: U radu se objašnjavaju osnove na kojima počiva 64-bitno računalstvo na stolnim računalima. Osim neophodnom 64-bitnom hardveru (mikroprocesori) posebna je pozornost posvećena i 64-bitnom softveru (64-bitni operacijski sustavi i 64-bitne aplikacije). Razmatrane su prednosti i nedostaci prelaska na 64-bitnu PC platformu.*

Ključne riječi: - 64-bitno računalstvo
- stolno računalo
- 64-bitni hardver
- 64-bitni softver

***Summary:** The paper explains the principles of 64-bit computing on a desktop computer. Besides 64-bit hardware (microprocessors), 64-bit software (64-bit operating systems and 64-bit applications) is also described in detail. The advantages and disadvantages of transition to a 64-bit platform are analysed.*

Key words: - 64-bit computing
- desktop computer
- 64-bit hardware
- 64-bit software

1. UVOD

U radu se nastoji objasniti osnovna razlika između 32-bitnih i 64-bitnih računala, koje su prednosti, a koji nedostaci 64-bitnih računala. Da bi se moglo govoriti o 64-bitnom računalstvu na stolnim računalima, treba imati PC koji ima 64-bitni mikroprocesor, 64-bitni operacijski sustav i 64-bitnu aplikaciju.

64-bitno računalstvo koristi se više od 10 godina u superračunalstvu i upravljanju velikim bazama podataka (DEC, IBM, Motorola...). Mnoge tvrtke i organizacije koje rade s velikom količinom podataka već koriste 64-bitne servere radi učinkovitijeg baratanja velikim brojem datoteka. U tom smislu jedan 64-bitni server može zamijeniti više 32-bitnih servera na mreži.

Pojmovi "64-bitnost" odnosno "32-bitnost" odnose se na određene karakteristike glavnoga procesora (CPU – Central Processor Unit). 64-bitni procesori imaju općenamjenske registre (GPRs – General Purpose Registers) širine 64 bita, dok 32-bitni procesori imaju opće namjenske registre širine 32 bita. U prošlosti su osobna računala imala te registre širine 16 bita (XT 8086), zatim 32 bita (80386), a danas imamo uglavnom 64-bitne registre.

Osnovne su prednosti 64-bitnih stolnih računala u odnosu na 32-bitna: veća količina radne memorije koju mogu koristiti i bolje performanse u nekim aplikacijama. 64-bitna računala imaju spomenute prednosti zato što

1. INTRODUCTION

This paper tries to explain what 64-bit computing is all about, what the difference is between 32-bit and 64-bit computers, and what advantages and disadvantages they have. If we could talk about 64-bit computing on desktop computers, we would have to use a 64-bit microprocessor, 64-bit operating system and a 64-bit application.

64-bit computing has been used for more then 10 years in supercomputing and data management systems (DEC, IBM, Motorola...). Many firms and organizations, which deal with great amount of data, are already using 64-bit servers because of more effective management with a great number of files. With regard to that, one 64-bit server could replace a number of 32-bit network servers.

The concepts "64-bitness" and "32-bitness" relate to certain characteristics of the main processor (CPU – Central Processor Unit). 64-bit processors have general-purpose registers (GPRs) that are 64 bit wide, while 32-bit processors have 32 bit wide GPRs. In the past, personal computers had 16 bit wide GPRs (XT 8086), then 32 bit wide (80386), and today general purpose registers are mainly 64 bit wide.

The basic advantages of 64-bit desktop computers regarding 32-bit desktop computers consist of the greater amount of working memory that they can use and better performance in some applications. Such advantages of

zbog veće širine općenamjenskih registara mogu baratati cijelim brojevima do 2^{64}, što je mnogo više od 2^{32} s koliko barataju 32-bitna računala.

2. 64-BITNO RAČUNALSTVO

Osnovna namjena općenamjenskih registara je skladištenje podataka koje procesor obrađuje, a to su ustvari brojevi. Računalo sve podatke tretira kao brojeve, a koliko velike brojeve procesor može obraditi ovisi o veličini općenamjenskih registara. Iz toga proizlazi osnovna prednost 64-bitnih procesora u odnosu na 32-bitne. 32-bitni procesori mogu izravno baratati cijelim brojevima u rasponu do 2^{32} (4.294.967.296), a kod 64-bitnih procesora taj se raspon povećava: oni mogu izravno baratati cijelim brojevima u rasponu do 2^{64} odnosno do nešto više od 18 kvadrilijuna (18.446.744. 073.709.551.616) [3].

Za većinu današnjih programa i aplikacija 32-bitni registri sasvim su dovoljni jer ne koriste cijele brojeve veće od 2^{32}. Kod nekih programa kao što su matematički programi, programi za simulaciju i modeliranje bilo koje vrste (npr. softver za modeliranje automobila i simuliranje njegova ponašanja u zračnom tunelu, softver za simulaciju kretanja atmosferskih prilika i predviđanje vremena itd.), kao i softver za kriptografiju, postoji potreba za 64-bitnim procesorima jer oni koriste cijele brojeve veće od 2^{32}. Oni se mogu normalno izvoditi i na 32-bitnim procesorima, samo je potrebno cijeli broj širi od 32 bita prelomiti na dva broja koja procesor zasebno obrađuje. Zbog toga se ti procesi izvršavaju znatno sporije nego na 64-bitnim procesorima. Osnovna je dakle prednost 64-bitnih procesora što u istom vremenu mogu procesirati dvostruko više podataka.

Povećanje općenamjenskih registara donosi još jednu prednost. U općenamjenskim se registrima ne spremaju samo podaci, nego i memorijske adrese (*pointeri* ili pokazivači). Memorijske adrese (upućuju procesor na lokaciju pojedinog podatka u radnoj memoriji računala) također su cijeli brojevi i stoga podložni ograničenjima općenamjenskih registara.

Memorijska adresa u 32-bitnom registru ne može biti veća od 2^{32}, 32-bitni procesor ne može adresirati više od 4 gigabajta RAM-a (RAM – *Random Access Memory*). S druge strane, 64-bitni procesor može adresirati čak 16 milijardi gigabajta memorije [3].

Instrukcijski registar (IR – *Instruction Register*), koji sadrži instrukciju koja se tog trenutka izvodi, iste je veličine kod 32 i 64-bitnog procesora (slika 1). To znači da je kod 64-bitnog procesora udvostručen protok podataka, ali ne i protok instrukcija. Isto tako moguće je vidjeti da je brojač programa (PC – *Program Counter*) udvostručen kod 64-bitnog procesora[4].

64-bit computers are the result of the larger size of general-purpose registers that enables them to process integers up to 2^{64}, which is much more than 2^{32} , that being the limit for 32-bit computers.

2. 64-BIT COMPUTING

General purpose registers act in storing numerical data processed by the processor. The computer handles all data as numbers, and the size of numbers that the processor can process depends on the size of the general-purpose registers. Accordingly, the main advantage of 64-bit processors regarding 32-bit processors is that 32-bit processors can directly process integers in a range of up to 2^{32} (4.294.967.296), but 64-bit processors can process integers in a range of up to 2^{64}, something more than 18.000.000.000GB (18.446.744.073.709.551.616) [3].

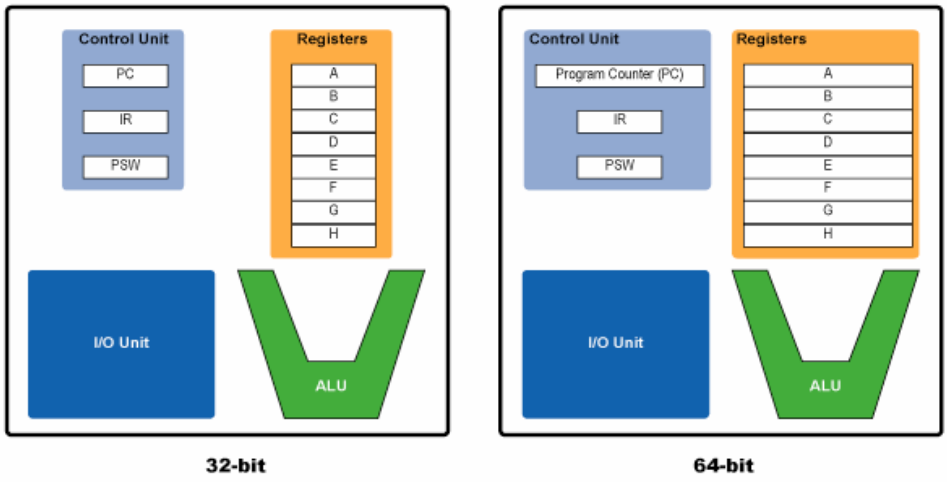
For most of today's programs and applications, 32-bit wide registers are sufficient, because they do not use integers larger than 2^{32}. Some programs such as mathematical programs, programs for simulation and modelling of any kind (e.g. software for modelling automobiles and simulation of its behaviour in an air tunnel, software for simulation of atmospheric condition movement and weather forecasting etc.), and software for cryptography, exihibit the need for a practical application for 64-bit processors which uses integers larger than 2^{32}. They can be normally processed on 32-bit processors, only some integer numbers larger than 32 bits have to be divided into two numbers that have to be processed separately. Because of that, these processes are executed much more slowly than on 64-bit processors, which can process double the data in the same amount of time.

The enlargement of general-purpose registers lends one more advantage. In general-purpose registers, not only is data stored, but also memory addresses (pointers). Memory addresses (that link the processor to the location of particular data in the working memory) are also integers and because of that, they are subject to the limitations of general-purpose registers.

Memory address in a 32-bit register cannot be larger than 2^{32}, and 32-bit processors can address no more than 4GB of RAM (RAM – Random Access Memory). On the other hand, 64-bit processors can address even 16 billion gigabytes of memory [3].

The size of the instruction register (IR) that holds currently executed instructions is the same in both a 32- and a 64-bit processor (Figure 1). It means that in a 64-bit processor, the data flow is doubled in size, but the instruction flow is not.

In addition, one can see that the program counter (PC) is doubled in the case of the 64-bit processor [4].



Slika 1. Usporedba 32-bitnog i 64-bitnog procesora [2]
Figure 1. Comparison between 32-bit and 64-bit processor [2]

Kod 32-bitnog procesora postoji mogućnost adresiranja memorije veće od 4GB poznata pod nazivom *Physical Address Extension* (PAE). PAE omogućuje 32-bitnom procesoru adresiranje do 64 gigabajta fizičke memorije uz uvjet da to podržava operacijski sustav i uz ograničenje da pojedini proces ne može vidjeti više od 4GB.

Većina 64-bitnih procesora umjetno ograničava svoj teorijski limit od 16 eksabajta radne memorije tako što ne dozvoljava memorijskim adresama da zauzmu puna 64 bita. To se radi zbog jednostavnosti i preformansi, a imajući na umu realne potrebe u sljedećim godinama. AMD64 arhitektura tako ograničava virtualni adresni prostor na 256 terabajta, a fizički adresni prostor na 1 terabajt. Virtualni adresni prostor predstavlja cjelokupnu memoriju kojoj procesor može pristupiti (virtualna memorija na disku i fizički RAM), dok fizički adresni prostor uključuje samo fizički RAM.

Da bi se iskoristile sve mogućnosti i prednosti 64-bitnog procesora, treba imati i 64-bitni operacijski sustav i 64-bitne aplikacije. To je i najveći problem koji ovoga trenutka usporava prelazak na 64-bitno računalstvo, jer trenutno 64-bitni softver nije jako rasprostranjen. Što se operacijskih sustava tiče, na tržištu se nalazi 64-bitni *Windows Server 2003*, *Windows XP Professional x64 Edition* te *Windows Vista x64 Edition*. Linux je potpunu podršku za AMD-ove 64-bitne procesore imao još ranije.

Međutim velika većina aplikacija i dalje je 32-bitna. 64-bitni softver uglavnom čine specijalizirane aplikacije koje nisu zanimljive većem krugu korisnika. Prebacivanje 32-bitnih aplikacija u 64-bitne nije tako jednostavno i mnogim proizvođačima softvera predstavlja velik trošak za relativno mali dobitak, jer većina običnih aplikacija pri prijelazu u 64-bitni oblik neće poboljšati performanse.

In a 32-bit processor, there is the possibility of addressing memory above 4GB, known as the Physical Address Extension (PAE). PAE enables 32-bit processor addressing of up to 64 gigabytes of physical memory in a case where the operating system supports that and with the limitation that one process cannot detect more than 4GB.

Most 64-bit processors artificially restrict their theoretical limit of 16 exabytes of working memory in a way that it does not allow memory addresses to occupy the full 64 bits. This is done for simplicity and performance reasons, and keeping in view the real needs in the years that follow. AMD64 architecture thereby restricts the virtual address space to 256TB, and the physical address space to 1TB. Virtual address space is the entire amount of memory that one processor can access (virtual memory is usually placed on the hard disc and physical RAM), while physical address space includes only physical RAM.

To use all the possibilities and advantages of a 64-bit processor we should also have a 64-bit operating system and 64-bit applications. This is also the biggest problem that at this moment does not allow for the transition to 64-bit computing, because today's 64-bit software is not widely used. Concerning the operating systems available on the market, there is a 64-bit *Windows Server 2003*, along with the Windows *XP Professional x64* Edition and *Windows Vista x64 Edition*. Linux even previously offered full support for AMD-s 64-bit processors.

However, most applications are still 32-bit. 64-bit software mostly consists of special applications that are not of special interest to common users. The translation of 32-bit applications into 64-bit applications is not so simple, and it means high costs for many software manufactures for a relatively small profit, because most ordinary applications at the translation into 64-bit form

Stare aplikacije praktički jednako dobro rade pod 64-bitnom i 32-bitnom inačicom operacijskog sustava. Logično rješenje bilo bi instaliranje 64-bitnih *Windowsa* da bi se iskoristile dostupne 64-bitne aplikacije, a da bi se istodobno mogli koristiti i stari programi.
Međutim postoje programi ili igre koji ne rade dobro pod novim operacijskim sustavima. Još je veći problem to što 64-bitni *Windowsi* zahtijevaju 64-bitne *drivere* za sve komponente u računalu. *Driveri* su softver koji radi na poprilično niskoj sistemskoj razini i trebaju biti maksimalno prilagođeni operacijskom sustavu.
64-bitni *Windowsi* dolaze s velikim brojem *drivera* za gotovo sve komponente, tako da će većina hardvera na tom operacijskom sustavu i raditi. No mnoge će komponente raditi znatno sporije nego na 32-bitnom sustavu, pa će zbog svega toga eventualni dobitak u performansama u pojedinim aplikacijama biti anuliran općenitom sporošću sustava.
Na serverskoj razini 64-bitnost trenutno ima mnogo više smisla nego na stolnoj, pogotovo na serverima koji upravljaju velikim bazama podataka (*SQL Server*, *Oracle* i dr.). Memorijski zahtjevi stalno rastu – stoga kada 4 gigabajta postane standardna količina RAM-a, to će biti jeftinije izvesti na 64-bitnom sustavu, a tada će i problemi s proširenošću 64-bitnog softvera i *drivera* nestati, te će većina aplikacija postati 64-bitna.

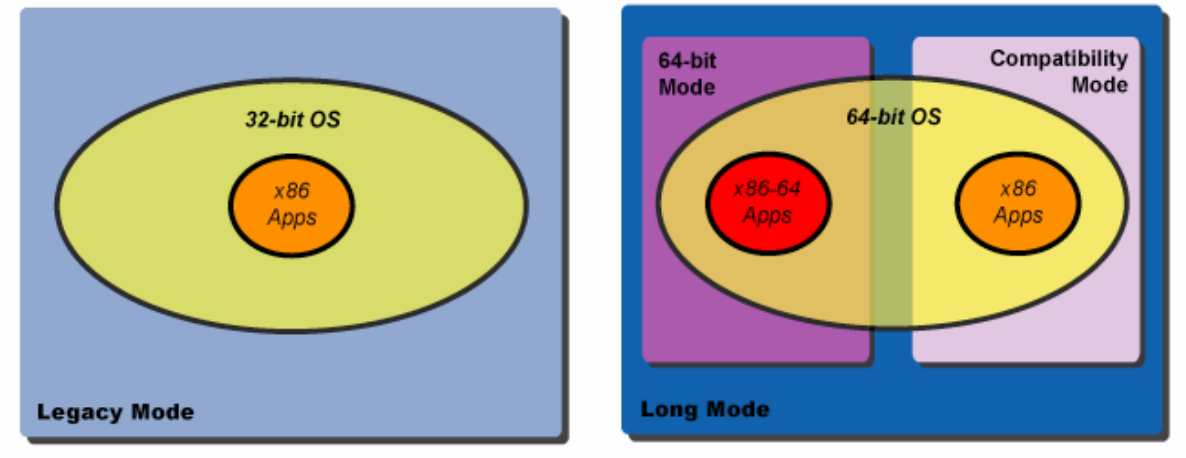
3. 64-BITNI MIKROPROCESORI

Svi su današnji 64-bitni mikroprocesori hibridni, tj. mogu raditi s 32-bitnim i 64-bitnim operacijskim sustavom. Hibridni instrukcijski set pod imenom *x86-64*, odnosno *AMD64*, izumila je tvrtka AMD za svoje mikroprocesore bazirane na arhitekturi K8. Cilj konstruiranja takva instrukcijskog seta bio je pružiti tržištu fleksibilno rješenje za prelazak s 32-bitnog na 64-bitni kod.
Praktično identičan instrukcijski set kasnije je prihvatio Intel dajući mu vlastito ime *EM64T*. *AMD64* i *EM64T* u potpunosti su kompatibilni, a razlike među njima bitne su isključivo programerima. *x86-64* je nadograđena inačica instrukcijskog seta *IA-32* odnosno *x86-32*. Proširenja seta općenito se mogu svesti na dodavanje podrške za 64-bitne registre opće namjene, 64-bitne aritmetičke i logičke operacije, te 64-bitno virtualno adresiranje. Procesori bazirani na toj arhitekturi mogu raditi na dva osnovna načina, ovisno o korištenom operacijskom sustavu. Mod *Legacy* koristi se kada je riječ o 32-bitnim ili 16-bitnim operacijskim sustavima i u tom slučaju nije moguće izvršavati 64-bitni kod [4]. Tzv. mod *Long* koristi se ako je na računalu instaliran 64-bitni operacijski sustav. Tada je moguće koristiti 64-bitne, ali i 32-bitne i 16-bitne aplikacije bez pada performansi jer su instrukcije podržane direktno u hardveru (slika 2).

will not improve their performance.The old applications in fact work almost equally well under the 64-bit and the 32-bit version of operating systems. The logical solution would be installing 64-bit *Windows* in order to use available 64-bit applications, and at the same time allowing for use of the old programs.
Nevertheless, there are programs or games that do not work well under new operating systems. Yet the bigger problem is that 64-bit *Windows* demand 64-bit drivers for all components in the computer. The *drivers* are software that works on a rather low system level and they should be maximally adapted to the operating system.
64-bit *Windows* come with a large number of *drivers* for almost all components, so most hardware will really work on this operating system. However, many components will work significally slower than on the 32-bit system, so because of all that, the eventual gain in performance for some applications will be cancelled by a general slowness of the system.
At the server level, 64-bitness makes much more sense than at the desktop level, especially on servers that manage large databases (*SQL Server, Oracle* etc.). The memory demands grow all the time and when 4 gigabytes becomes the standard amount of RAM, that will be cheaper to do on 64-bit system; and by then problems with the expansiveness of 64-bit software and *drivers* will be long gone, and most applications will become 64-bit ones.

3. 64-BIT MICROPROCESSORS

Currently all 64-bit microprocessors are hybrid, which means that they can work with 32-bit and 64-bit operating systems. The hybrid instruction set under the name *x86-64*, or *AMD64*, was invented by AMD for their microprocessors based on K8 architecture. The goal of such an instruction set design was to give a flexible solution to the market for translation from 32-bit into 64-bit code.
A practically identical instruction set was later accepted by Intel under its own name as *EM64T*. *AMD64* and *EM64T* are fully compatible, and differences between them have meaning only to programmers. *x86-64* is the upgraded version of the instruction set *IA-32*, or *x86-32*. The enlargements of sets are generally based on giving support for 64-bit general-purpose registers, 64-bit arithmetical and logical operations and 64-bit virtual addressing. Processors based on this architecture can work in two basic ways, depending on the operating system used. The *Legacy* Mode is used when it is about 32-bit or 16-bit operating systems and in this case, it is not possible to execute 64-bit code [4]. The so-called *Long* mode is used if the 64-bit operating system is installed on the computer. Then it is possible to use 64-bit, but also 32-bit and 16-bit applications without a drop in performance, considering that instructions are supported directly in the hardware (Figure 2).



Slika 2. Usporedba između Legacy i Long moda [2]
Figure 2. Comparison between Legacy and Long Mode [2]

Prvi Intelov 64-bitni procesor bio je *Itanium*. Prva inačica *Itaniuma* koju su razvili Intel i HP pod kodnim imenom *Merced* izašla je na tržište sredinom 2001. godine. Instrukcijski set koji su Intel i HP predstavili tim procesorom nosio je ime *IA-64* (*Intel Architecture 64*), a sama arhitektura bila je bazirana na principu zvanom *EPIC* (*Explictly Parallel Instruction Computing*).

Ne samo da *IA-64* arhitektura nije bila kompatibilna s arhitekturom *IA-32* (odnosno *x86*) unatoč sličnom imenu, nego su se dvije arhitekture fundamentalno razlikovale budući da je cijeli koncept *EPIC*-a baziran na tome da procesor nema sposobnost predviđanja grananja (*branch prediction*), već je to prepušteno softveru [1].
Također, *Itanium* nije imao podršku za „out of order execution“ poput svih modernijih *x86* ili *x86-64* procesora. Premda su *IA-32* instrukcije kod *Itaniuma* bile mapirane na funkcijskim jedinicama, sama arhitektura procesora (*EPIC*) onemogućavala je efikasno izvršavanje novih instrukcija, pa je pad performansi kod izvršavanja starih aplikacija bio vrlo velik.
AMD je svojom arhitekturom *x86-64* (odnosno *AMD64*) napravio mnogo fleksibilniji pristup (slika 3). AMD je slijedio logiku da je za prelazak na 64-bitno računalstvo potrebno imati procesor koji jednako dobro radi s postojećim i novim aplikacijama.
IA-32 instrukcijski set u potpunosti je zadržan, a arhitektura je proširena sa 64-bitnim registrima zbog čega je taj procesor, s takvom arhitekturom, kompatibilan sa svim starim aplikacijama, a s odgovarajućim 64-bitnim operacijskim sustavom može raditi sa 64-bitnim aplikacijama.

The first Intel 64-bit microprocessor was *Itanium*. The first version of *Itanium* developed by Intel and HP under the code name *Merced* entered the market in the middle of 2001. The instruction set which is presented by Intel and HP with this processor was *named IA-64* (*Intel Architecture 64*), and this particular architecture was based on a principle called *EPIC* (*Explitly Parallel Instruction Computing*).

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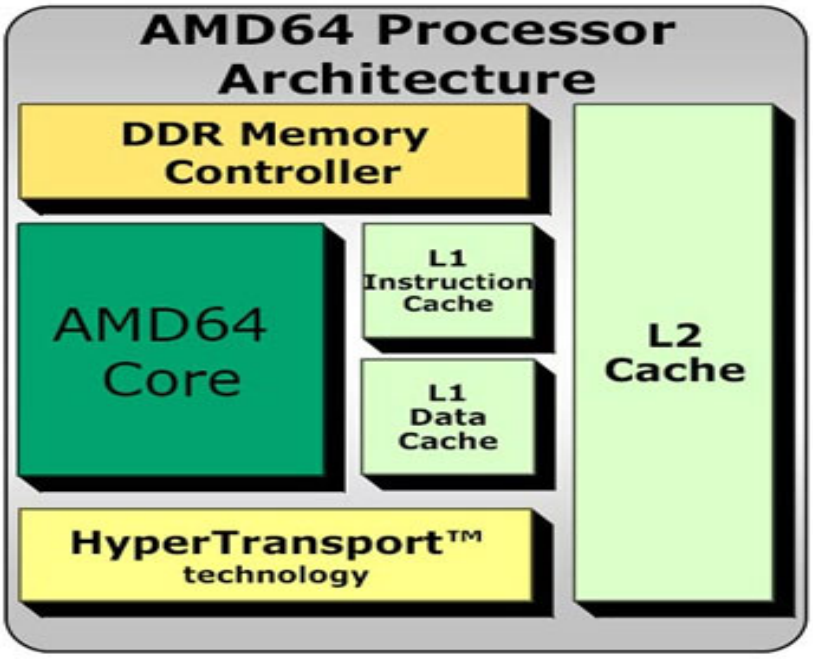
Not only was *IA-64* architecture not compatible with *IA-32* architecture (or *x86*) in spite of the similar name, but rather the two architectures where fundamentally different in that the whole concept of *EPIC* was based on the incapability of the processor to predict branching (*branch prediction)*, so that was left to the software [1].
What is more, *Itanium* did not have support for the "out of order execution" like any modern *x86* or *x86-64* processor. Although *IA-32 Itanium* instructions were mapped on functional units, the architecture of the processor (*EPIC*) did not allow for the effective execution of new instructions, so the drop in performance of execution of the old instructions was extremely high.
AMD made with its architecture of *x86-64* (or *AMD64*) a much more flexible approach (Figure 3). AMD followed the logic that for the transition into 64-bit computing we need to have a processor that runs existing and new applications equally well.
The *IA-32* instruction set was completely kept, and the architecture was enlarged with 64-bit registers, so because of that this processor is compatible with all older applications, and with an appropriate 64-bit operating system it can run 64-bit applications.



Slika 3. Shema AMD mikroprocesora [4]
Figure 3. Scheme of AMD microprocessor [4]

S obzirom na navedeno, sasvim je logično što je arhitektura *x86-64*, a ne arhitektura *IA-64* pokrenula prelazak na 64-bitno računalstvo na stolnim računalima i jeftinijim serverima. Vrlo visoka cijena, nekompatibilnost sa softverom i problemi s performansama ostavili su procesore bazirane na arhitekturi *IA-64* u domeni specijaliziranih računalnih sustava.
Upravo je arhitektura *x86-64* pomogla AMD-u da se iz tvrtke koja kopira Intelove inovacije i nudi ih po pristupačnoj cijeni pretvori u svojevrsnoga tržišnog lidera, možda ne što se tiče tržišnog udjela, ali tehnološki svakako.

Vjerojatno je najveći dokaz za to Intelovo izdavanje procesora koji podržavaju gotovo identičan instrukcijski set. Naime *EM64T*, Intelov *x86-64* instrukcijski set, kompatibilan je s AMD-ovim, a razlikuje se samo u nekim detaljima.
Što se tiče ostalih komponenti računala, one mogu ostati 32-bitne, jer se 64-bitnost kod današnjih osobnih računala svodi na pravilnu kombinaciju procesora i odgovarajućega operacijskog sustava koji može iskoristiti njegove dodatne instrukcije. Jedini su problem 64-bitni *driveri* koji omogućuju da sve komponente koje imamo u računalu rade u kombinaciji sa 64-bitnim operacijskim sustavom.

Regarding such matters, it is completely logical that *x86-64* architecture, and not *IA-64* architecture, started the transition to 64-bit computing on desktop computers and lower-end servers. An extremely high price, incompability with software and problems with performance left the processors based on *IA-64* architecture in the domain of specialised computer systems.
It was precisely *x86-64* architecture that helped AMD to translate itself from a firm that copies Intel innovations and offers them at accessible prices to some kind of market leader.
Maybe not in terms of market share, but certainly technologically.
Probably the biggest proof for that is the release of processors that support an almost identical instruction set by Intel. *EM64T*, the Intel *x86-64* instruction set, is compatible with that of AMD, and the difference between them is found only in a few details.
With regard to other computer components, they remain 32-bit because 64-bitness in today's personal computers is based on the right combination of processor and corresponding operating system that can use its supplemental instructions. The only problem is 64-bit *drivers* that allow all available components in the computer to work in combination with a 64-bit operating system.

Glavna je namjena grafičkog procesora omogućivanje napredne 3D-grafike, a za to jednostavno nije osobito korisno rabiti 64-bitne registre. Skok na 64-bitnu preciznost nije dovoljno isplativ jer je rast kvalitete prikaza vrlo malen, praktički neprimjetan, dok je za implementiranje 64-bitnih registara potrebno dodati popriličan broj tranzistora.

3. 64-BITNI OPERACIJSKI SUSTAVI

3.1. Windows XP Professional x64 Edition

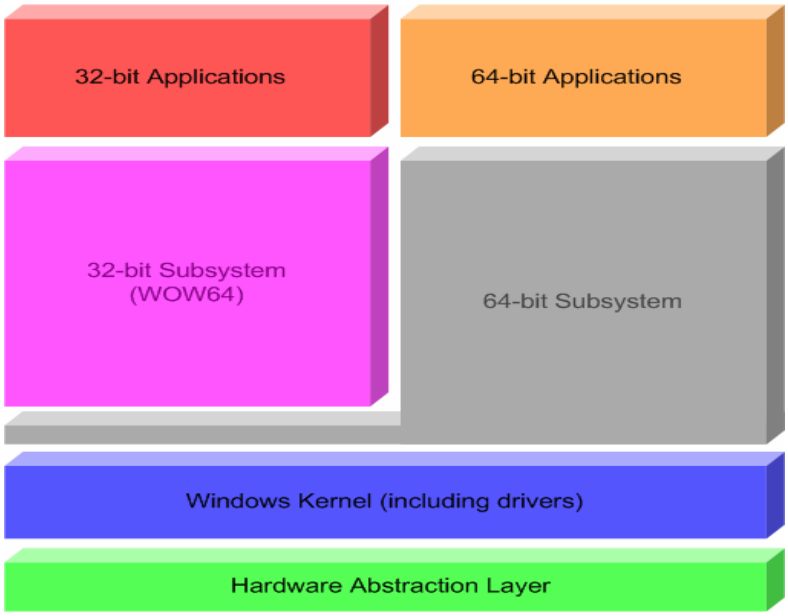
Odmah nakon izdavanja *Athlona64* izašla je i 64-bitna inačica Linuxova kernela za taj procesor, ali širenje 64-bitnog računalstva na PC-u nije se moglo očekivati prije nego što Microsoft izda 64-bitne inačica svojih operacijskih sustava. Microsoft je s time podosta otezao, a razlozi za to više su bili političke nego tehničke naravi. Microsoft je dugo slovio za najvećega Intelova saveznika. Stoga nije čudno da je izdavanje 64-bitnih *Windowsa* uslijedilo tek nakon što je Intel izdao svoje procesore kompatibilne s *Athlon64*.

The main reason for using a graphic processor is the enablement of advanced 3D graphics, and for this purpose, it is not very useful to use 64-bit registers. The jump to 64-bit precision is not productive enough because the improvement in display quality is very small, practically invisible, and for implementing 64-bit registers, you must add a large number of transistors.

3. 64-BIT OPERATING SYSTEMS

3.1. Windows XP Professional x64 Edition

Immediately after the release of *Athlon64,* Linux introduced a new 64-bit version of the Linux kernel for that processor, but the initiation of 64-bit computing on PC was not expected before Microsoft delivered its 64-bit version of its operating systems. Microsoft delayed long enough, and the reasons for that were more political than technological. Microsoft was considered for a long period to be Intel's major ally. Thus, it was not strange that the delivery of 64-bit Windows followed after Intel had delivered processors compatible with *Athlon64*.



Slika 4. Windows XP Pro x64 arhitektura [4]
Figure 4. Windows XP Pro x64 Architecture [4]

Windows XP Professional x64 Edition, što je puni naziv 64-bitnih *Windowsa XP*, zasnovan je na kodu *Windows Servera 2003 SP1* i stoga je u startu sigurniji i stabilniji nego obični 32-bitni *Windows XP* (slika 4).

Windows XP Professional x64 Edition, with the complete specification being 64-bit *Windows XP*, is based on *Windows Server 2003 SP1* code and thus from the start it is more secure and stable than ordinary 32-bit Windows XP (Figure 4).

64-bitna inačica *Windowsa* može adresirati 128 gigabajta fizičkog RAM-a i 16 terabajta virtualne memorije. U 64-bitnoj inačici uklonjeno je i ograničenje od dva gigabajta memorijskog prostora po procesu. Kako bi se zadržala kompatibilnost s 32-bitnim softverom u *XP-u x64* implementiran je takozvani WOW64 emulator 32-bitnih *Windowsa* pod kojim se vrte sve stare aplikacije. Taj je proces u potpunosti transparentan za korisnike, 32-bitne aplikacije pokreću se kao i sve druge aplikacije i korisnik se uopće ne mora brinuti je li riječ o starim programima. Iznimka je jedino softver koji zadire dublje u sistem poput antivirusnog alata, vatrozida ili defragmentatora – on na novim *Windowsima* jednostavno neće raditi i potrebno je nabaviti nove 64-bitne inačice.
Široko prihvaćanje 64-bitnih *Windowsa* koči nedostatak *drivera*. Naime stare 32-bitne *drivere* nije moguće ni na koji način koristiti u 64-bitnim *Windowsima*. Zbog nedovoljno velike korisničke baze mnogi proizvođači još uvijek ne isporučuju 64-bitne *drivere* za svoje nove komponente, a kamoli da se bave razvijanjem 64-bitnih *drivera* za starije uređaje, pogotovo koji nisu u prodaji. Međutim novi *Windowsi* dolaze s velikom količinom generičkih *drivera*, tako da će većina komponenti i periferija raditi, ali zato što su ti *driveri* uglavnom neoptimizirani, često ne podržavaju sve opcije koje uređaj nudi.
Za *drivere* koji su potrebni na serverima proizvođači su se obično unaprijed pobrinuli, a što se tiče aplikacija, na raspolaganju su one koje i imaju najviše koristi od 64-bitnih procesora: među njih se ubrajaju sve popularnije baze podataka (uključujući *MS SQL Server* i *Oracle*).

3.2 Windows Vista x64 Edition

Prvi operacijski sustav za osobna računala koji ravnopravno nudi i 64-bitnu inačicu po istoj cijeni kao i 32-bitnu je operacijski sustav *MS Windows Vista*.
Ako usporedimo 64-bitnu i 32-bitnu inačicu *Viste* što se tiče performansi, vidimo da je 64-bitna inačica brža kod izvođenja programa koji barataju s vrlo velikim cijelim brojevima, kao što su matematički softveri, CAD/CAM aplikacije i alati za obradu videa. Za ostale aplikacije dobitak u performansama ne postoji pa ne možemo tvrditi da je 64-bitna inačica apsolutno bolja od 32-bitne inačice. Što se tiče kompatibilnosti, načelno se svi programi za *Windowse* mogu izvoditi na 64-bitnoj inačici *Viste*, ali u praksi to i nije tako. Mnogi programi koji koriste osobitosti 32-bitne inačice mogu na 64-bitnoj imati problema. Isto tako 32-bitni programi koji zadiru duboko u sustav poput sigurnosnog i antivirusnog softvera neće ispravno raditi, a 32-bitni *driveri* uopće ne rade na 64-bitnoj inačici operacijskog sustava.
Sigurnost je područje u kojem je 64-bitna inačica uvjerljivo bolja od 32-bitne. U 64-bitnu inačicu ugrađeni su mehanizmi koji sprečavaju softver da zamijeni kernelove funkcije svojima. To je u početku zasmetalo

The 64-bit version of *Windows* can address 128 gigabytes of physical RAM and 16 terabytes of virtual memory. In the 64-bit version, the restriction of using only two gigabytes of memory space per one process is removed. To maintain compatibility with 32-bit software in *XP x64,* the so-called WOW64 emulator was implemented to 32-bit *Windows*, under which all old programs remain applicable. This process is entirely transparent for users, the 32-bit applications run like all other applications, and the user does not need to care at all if old programs are involved. The exception is only the software that delves deeply into the system, like antivirus tools, firewall or defragmentator, so this software simply will not work on the new *Windows* and more current 64-bit versions must be provided.
Widespread acceptance of 64-bit *Windows* suffers because of a lack of drivers. Namely, the old 32-bit drivers cannot to be used in any way in 64-bit *Windows*. Because there are not yet enough users, many manufactures still do not provide 64-bit drivers for their new components; much less do they care about development of 64-bit *drivers* for older devices, especially if they are out of sale. However, the new *Windows* comes with a great amount of generic drivers, so most components and periphery will work, but because these *drivers* are generally not optimised, frequently not all options that are offered by a particular device will be supported. Manufactures usually take care in advance to provide *drivers* that are needed on servers, and as regards available applications, there are those that have a major benefit from 64-bit processors and among them are all of the more popular databases including *MS SQL* and *Oracle*.

3.2 Windows Vista x64 Edition

The first operating system for desktop computers that equally offers a 64-bit version at the same price as the 32-bit version is the *MS Windows Vista* operating system. Comparing the 64-bit and the 32-bit version of Vista in performance we can see that the 64-bit version is faster at running programs which use very large integers, like mathematical software, CAD/CAM applications and tools for video processing. For other applications, the gain in performance does not exist, so we cannot say that the 64-bit version is absolutely better then the 32-bit one. As far as the matter of compatibility, almost all programs for *Windows* can run on the 64-bit version of *Vista*, but in fact, it is not like that. Most programs which use characteristics of the 32-bit version on a 64-bit platform can have problems. In addition, 32-bit programs that delve deeply into the system like security and antivirus software will not work correctly, and 32-bit *drivers* will not work at all on the 64-bit version of the operating system.
Security is an area in which the 64-bit version is convincingly better than the 32-bit one. In the 64-bit version there are built in components, which do not allow

mnogim proizvođačima anitvirusnog softvera koji su tu funkcionalnost koristili za svoje programe, no nedostatak te mogućnosti donekle sprečava pisce zlonamjernoga softvera u preuzimanju kontrole nad računalom. Također 64-bitna inačica ima još prednosti koje osiguravaju veću sigurnost uključujući i insistiranje na tome da svi *driveri* budu certificirani.
Upravo su *driveri* najveći problem koji već nekoliko godina koči široko prihvaćanje 64-bitnih *Windowsa*, a ni Vista u tome nije iznimka. Naime 32-bitne *drivere* nemoguće je koristiti u 64-bitnim *Windowsima*. Jedino proizvođači grafičkih kartica izdaju 32-bitne i 64-bitne *drivere*, dok ih ostali proizvođači uglavnom ne proizvode. *Driveri* za mnoge kernelove komponente i periferije, pogotovo one starije, nikada neće ni postojati u 64-bitnoj inačici.

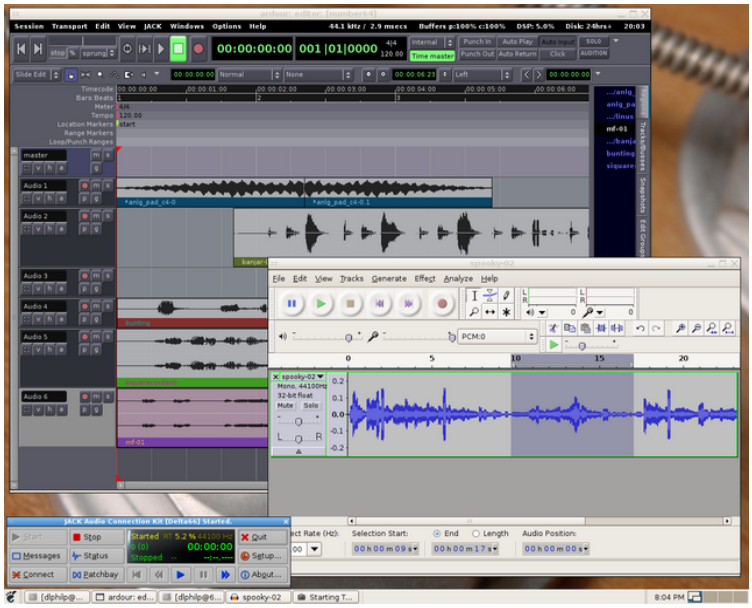
3.3 64-bitni Linux

Današnja jezgra Linuxa pokreće se na bilo kojoj arhitekturi, od mobitela do super računala, a u toj se lepezi nalazi, naravno, i x86-64 arhitektura. Jezgra Linuxa prvi je put prebačena na 64-bitnu arhitekturu još pradavne 1993. godine, tako da podrška za 64-bitne procesore nije nikakva posebnost za GNU/Linux sustave, ali dosad je primarna platforma uvijek bila 32-bitna x86.
Linux i *open source* softver danas su u vrlo dobroj poziciji što se tiče prilagođenosti 64-bitnim mikroprocesorima, upravo zbog dugih godina iskustva i zbog od početka poznatih programskih načela koja osiguravaju da će se aplikacija kompilirati i izvršavati u 64-bitnim uvjetima. 64-bitni Linux prisutan je već više od desetljeća pa tako i na x86-64 arhitekturi izgleda uvjerljivo. Od pet najpopularnijih distribucija Linuxa četiri imaju potpuno podržane i 32-bitnim inačicama ravnopravne 64-bitne varijante (*Ubuntu*, *SUSE*, *Fedora* i *Mandriva*) te gotovo da nema razloga da korisnici ne bi odabrali 64-bitne inačice, iako ni u Linuxu nije sve savršeno.
Najveći problemi vezani su uz programe zatvorenoga koda koji još nisu izdani u 64-bitnoj varijanti, kao što su *plug-inovi* za *web*-preglednike, no i za te probleme postoji rješenje. Zahvaljujući arhitekturi koju ima x86-64, odnosno sposobnosti takvih procesa da izvršavaju i 32-bitni i 64-bitni kod, pod 64-bitnim Linuxom moguće je izvršavati i 32-bitne aplikacije, te će većina Linuxa za šire mase to raditi potpuno transparentno za krajnjega korisnika. Sistem se zasniva na takozvanom *multilib* načinu kompiliranja programa, odnosno postojanju i 32-bitnih i 64-bitnih biblioteka na sustavu, a programi koriste one biblioteke koje im odgovaraju. Jedino još nije prevladano ograničenje da 64-bitni programi ne mogu koristiti 32-bitne biblioteke.
Kod problema s *driverima* do izražaja dolazi otvorenost jezgre sustava, pa je prilagodba postojećih *drivera* za nove arhitekture je jednostavna. Normalno je da hardver koji radi sa *driverima* u 32-bitnom kernelu također radi i u 64-bitnom kernelu.

the software to replace the kernel functions with its own. In the beginning, that irritated many manufactures of antivirus software that used this functionality for their programs, but lack of this possibility at some point does not allow writers of malicious software to overtake the computer controls. The 64-bit version also has advantages that ensure more security including that it insists that all *drivers* must be certified.
In particular, *drivers* are the biggest problem of the widespread circulation of 64-bit *Windows* for many years already, so Vista is not an exception. Namely, 32-bit *drivers* are impossible to use in 64-bit *Windows*. Only the manufactures of graphic cards deliver 32-bit and 64-bit drivers, still the situation with others is quite bad. The *drivers* for many components and peripheries, especially for the older ones, will never exist in the 64-bit version.

3.3 64-bit Linux

Today's Linux kernel can run on any architecture, from cellulars to supercomputers, and in this range there is, of course, also x86-64 architecture. The linux kernel was for the first time installed on 64-bit architecture in 1993, thus the support for 64-bit processors is not something special for GNU/Linux systems, but until now the primary platform was always 32-bit x86.
Linux and *open source* software are today in a very good position regarding adaptation to 64-bit microprocessors, exactly because of long years of experience and because from the beginning of known program principles they ensured that the application would be be compliable to and executable in 64-bit conditions. 64-bit Linux has been present for more than a decade, so also on the x86-64 architecture it looks convincing. Among five of the most popular Linux distributions there are four which have fully supported 32-bit versions equal to 64-bit alternatives (*Ubuntu, SUSE, Fedora* and *Mandriva*), and there is virtually no reason why users would not choose 64-bit versions, though everything is not perfect even in Linux.
The biggest problems are connected with closed source programs that are not yet delivered in the 64-bit version, such as plug-ins for web browsers, but also for those problems, there is a solution. Thanks to x86-64 design architecture and the ability of such processes to execute 32-bit as well as 64-bit code, under 64-bit Linux it is possible to also execute 32-bit applications, and most Linux systems will universally run this fully transparently for the end user. The system is based on the so-called multilib way of compiling programs, or on existing and also on 32-bit and 64-bit libraries in the system, and programs use those libraries that suit them. The only restriction that is not yet established is that 64-bit programs cannot use 32-bit libraries.
Along with the problems with drivers, the openness of the system kernel becomes prominent, so the adjustment of the existing drivers for new architectures is simple.



Slika 5. Linux 64 Studio
Figure 5. Linux 64 Studio

Na slici 5 je korisničko sučelje audiooptimizirane Linux distribucije (64 Studio) bazirane na 64-bitnom *Debianu* namijenjene potrebama multimedijskih korisnika.

3.4 *64-bitni Mac OS X*

Nakon Appelova razlaza s Motorolom, suradnja s IBM-om donijela je prve 64-bitne procesore na Macintoshu. Macintoshi s procesorima G5 pojavili su se još u lipnju 2003. godine. U to vrijeme aktualni *Mac OS X 10.2* (*Jaguar*) nije bio u stanju iskoristiti išta od 64-bitnih mogućnosti novih procesora sve dok se u listopadu iste godine nije pojavio *Mac OS X 10.3* (*Panther*).
Iako bi ga teško bilo nazvati 64-bitno kompatibilnim, *Mac OS X 10.3 Panther* postavio je temelje za 64-bitne operacije na Appleovim računalima. Tom je inačicom *Mac OS X* ponudio 64-bitno adresiranje virtualne memorije u kernelu te omogućio kernelu uporabu 64-bitnih registara i instrukcija, dok su svi ostali procesi još uvijek bili 32-bitni. U praksi je to značilo da je sustav mogao iskoristiti više od 4 gigabajta sistemske memorije, odnosno maksimalno 8 gigabajta, koliko je moguće ubaciti u G5 računala, ali pojedina aplikacija nije mogla koristiti više od 4 gigabajta radne memorije.
U travnju 2005. godine izlaskom *Mac OS X 10.4* (*Tiger*) Apple je napravio idući korak u smjeru potpune 64-bitnosti. U *Tigeru* je omogućeno 64-bitno adresiranje bilo kojem procesu koji u svojem kodu može koristiti 64-bitne instrukcije. Jedini 64-bitni sloj sistema u *Mac OS X 10.4* (*Tigeru*) jest *libSystem* odnosno BSD sloj koji sadrži većinu bazičnih UNIX API-a. Tu se nalazi i 32-bitni *libSystem* bez kojega ne bi radili 32-bitni

Figure 5 shows the user interface of the audio-optimized Linux distribution (64 Studio) based on the 64-bit *Debian* system that is devoted to the needs of multimedia users.

3.4 64-bit Mac OS X

After Apple's split with Motorola, cooperation with IBM led to the first 64-bit processors in the Macintosh. Mac's with G5 processors appeared in July 2003. In that time the actual *Mac OS X 10.2* (*Jaguar*) was not able to use any of the 64-bit capabilities of the new processors, until in October of the same year when the *Mac OS X 10.3* (*Panther*) made an appearance.
Though it is hard to call it 64-bit compatible, the *Mac OS X 10.3 Panther* established the foundations for 64-bit operations on Apple computers. With this version of the *Mac OS X* was offered 64-bit virtual memory addressing in kernel, and it also enabled to kernel the usage of 64-bit registers and instructions, though all other processes were still 32-bit ones. In fact, it meant that the system could use more then 4 gigabytes of system memory; or at the utmost the 8 gigabytes that is possible to load into G5 computers, but a single application could not use more than 4 gigabytes of working memory.
In April 2005, with phasing out of the *Mac OS X 10.4* (*Tiger*), Apple took the next step in the direction of full 64-bitness. In *Tiger* 64-bit, addressing was enabled in any process that in its code could use 64-bit instructions. The only 64-bit system layer in the *Mac OS X 10.4 Tiger* was the libSystem, apropos the BSD layer that holds most basic UNIX APIs. There is also the 32-bit libSystem without which 32-bit programs would not work. This is support for 32-bit and for 64-bit applications.

programi. Sve skupa predstavlja podršku kako za 32-bitne tako i za 64-bitne aplikacije.
64-bitna podrška namijenjena je uglavnom znanstvenim aplikacijama poput *Wolfram Research Mathematice*. Postoji mogućnost *Mac OS-a X* da istodobno pokreće 32-bitni *Photoshop 10* i 64-bitnu *Mathematicu 6* (7) koristeći sistemsku memoriju od 8 gigabajta [3].
Poslije je Apple predstavio i inačicu *Mac OS X 10.5* (*Leopard*). Za razliku od *Tigera*, svi su dijelovi sistema u *Leopardu* 64-bitni tako da istodobno omogućuju potpunu kompatibilnost s 32-bitnim i 64-bitnim programima.

4. ZAKLJUČAK

Unatoč svim dosad navedenim problemima stanje nije tako loše što se tiče 64-bitnog softvera. Postoje aplikacije koje treba nadograditi kako bi uopće funkcionirale na 64-bitnim operacijskim sustavima. Postoje i aplikacije koje zaista pokazuju opravdane prednosti kod prelaska na 64-bita. To su aplikacije s velikim zahtjevima za memorijom, kod kojih unaprijeđeno upravljanje memorijom te podrška za velike količine memorije kod 64-bitnih sustava dolaze do izražaja.
Osjetna ubrzanja prisutna su i kod matematički zahtjevnijih aplikacija kao što su npr. aplikacije za 3D-renderiranje, procesiranje zvuka, slike i videa, kompresiju i dekompresiju, enkripciju i dekripciju.
Treba spomenuti i specijalne matematički zahtjevne aplikacije koje se koriste u znanstvene svrhe (npr. Wolfram Researchova *Mathematica 6*), kod kojih 64-bitni sustavi pokazuju svoju snagu ne samo unaprijeđenim rukovanjem memorijom, nego i registrima koji omogućuju lakše i precizne izračune. Ostali primjeri takvih aplikacija su *Photoshop CS3*, *Maxon Cinema 4D*, *Lightwave*, *Maya*, *Blender* i drugi. Neki od njih vuku beneficije od korištenja 64-bitnog sustava samo u pogledu podrške za veću količinu memorije (npr. *Photoshop CS3*), dok je kod drugih riječ o ubrzanjima na račun nove arhitekture.

64-bit support is assigned mainly to scientific applications like *Wolfram Research Mathematica*. There is the possibility that *Mac Os X* will simultaneously run 32-bit Photoshop 10 and 64-bit Mathematica 6 (7) using 8 gigabytes of system memory [3].
Later on, Apple also presented the *Mac OS X 10.5* version (*Leopard*). Unlike *Tiger*, all of the system parts in *Leopard* are 64-bit so they simultaneously enable full compatibility with 32-bit and 64-bit programs.

4. CONCLUSION

In spite of the aforementioned problems, not everything is all bad regarding 64-bit software. There are applications that must be upgraded so they can function on 64-bit operating systems at all. There are also applications that really show justified advantages in the transition to 64-bit. Those are applications with big demands for memory, in which the advanced memory managing and support for high memory requirements in 64-bit systems becomes prominent.
Appreciable accelerations are present also in mathematically demanding applications like 3D rendering, sound processing, image and video processing, compression and decompression, encryption and decryption.
Remarkable speed increase occurs in mathematically demanding applications which are used for scientific purposes (e.g. Wolfram Research's *Mathematica 6*), with which 64-bit systems show their strength not only in terms of advanced memory management, but also with registers that enable easier and more precise calculations. Other examples of such applications are *Photoshop CS3*, *Maxon Cinema 4D*, *Lightwave*, *Maya*, *Blender* and others. Some of them have benefits over using a 64-bit system only in support for a larger amount of memory (e.g. *Photoshop CS3*), while with others it is about accelerations on account of the new architecture.

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Primljeno / Received: 30.4.2008
Prihvaćeno / Accepted: 17.6.2008

Strukovni prilog
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