RUDN Journal of Psychology and Pedagogics
Вестник РУДН. Серия: Психология и педагогика
2017 Vol. 14 No 1 17—25
http://journals.rudn.ru/psychology-pedagogics

DOI 10.22363/2313-1683-2017-14-1-17-25
UDK 159.9.07

# WORKING MEMORY STRUCTURE REVEALED IN ANALYSIS OF RECALL ERRORS

**R.V. Ershova**

State University of Humanities and Social Studies
*Zelenaya str., 30, Kolomna, Russia, 140410*

**E. Tarnow**

Avalon Business Systems, Inc.
*18-11 Radburn Road, Fair Lawn, NJ 07410, USA*

**Abstract.** We analyzed working memory errors stemming from 193 Russian college students taking the Tarnow Unchunkable Test utilizing double digit items on a visual display.

In three-item trials with at most one error per trial, single incorrect tens and ones digits ("singlets") were overrepresented and made up the majority of errors, indicating a base 10 organization.

These errors indicate that there are separate memory maps for each position and that there are pointers that can move primarily within these maps. Several pointers make up a pointer collection. The number of pointer collections possible is the working memory capacity limit. A model for self-organizing maps is constructed in which the organization is created by turning common pointer collections into maps thereby replacing a pointer collection with a single pointer.

The factors 5 and 11 were underrepresented in the errors, presumably because base 10 properties beyond positional order were used for error correction, perhaps reflecting the existence of additional maps of integers divisible by 5 and integers divisible by 11.

**Key words:** working memory, working memory errors, integer representation in working memory, memory maps, pointer

## Introduction

Working memory (WM) is considered as a multi-components model of short-term memory, a human ability to work with information, which plays an important role in learning from kindergarten to the college years (Alloway, 2010).

Recent technological and methodological development have led to increase in studies of WM models (including the levels and capacity of WM, neural executive mechanisms of WM, it`s brain localization and links with IQ, language and speech) (Phillips, & Christie, 1977; Donald, 1991; Baddeley, 2001; Erricsson, & Kintsch, 1995, Houde & Tzourio-Mazoyer, 2003; Broadbent, 1975; Cowan, 2012).

Studies have revealed that WM is important for a variety of activities at school: reading comprehension, mental arithmetic (Gathercole, Alloway, Willis & Adams, 2006; Nation, Adams, Bowyer-Crane, & Snowling, 1999; Swanson & Saez, 2003; Alloway & Gregory, 2013), and that it is involved in directing attention to a task despite distraction or interference (Cowan, 2006; Engle et al., 1999). Measures of WM have been found to correlate with intellectual aptitudes better than measures of short-term memory and possibly better than measures of any other particular psychological process (Daneman, & Carpenter, 1980; Kyllonen, & Christal, 1990; Engle et al., 1999; Conway et al., 2005).

Researchers have also analyzed the impact of environment (e.g. socio-economic status) (Lynch, Kaplan et al., 1997; Noble, McCandliss, & Farah, 2007), the task attitude (task-set switching) (Allport & Wylie, 1999), effects on subjects with attention deficit (de Lima Ferreira et al, 2015) and personal characteristics (e.g. the interest) (Ericsson, 1995) on WM.

The main objective of this article is to analyze WM errors for the same category items within the capacity limit. This is a relatively new inquiry in the sense that previous work on errors did not limit itself to working memory. They were focused on general recall (for example, Henson et al (1996); Tarnow, 2015b), different category items (Byrne, & Bovair, S. 1997), different tasks (Bull, & Scerif, 2001), multiple categories in working memory such as the Stropp task (Engle, 2002), different channels (Moray, 1959) and tasks that go beyond the capacity limit (Luck, & Vogel, 1997).

The results of our investigation may be important for understanding the structure of WM, for designing new empirical studies to advance theory and research in this area, as well as measuring the effectiveness of the methodological tools needed to test WM.

## Method

We present data from a study of university students aged 17 to 24.

The Tarnow Unchunkable Test (TUT) used in this study separates out the WM component of free recall by using particular double-digit combinations which lack intra-item relationships (Tarnow, 2013). The TUT was given via the internet using client-based JAVAScript to eliminate any network delays. The instructions and the memory items were displayed in the middle of the screen. Items were displayed for two seconds without pause. The trials consisted of 3 or 4 items after which the subject was asked to enter each number remembered separately, press the keyboard enter button between each entry and repeat until all the numbers remembered had been entered. Pressing the enter button without any number was considered a “no entry”. The next trial started immediately after the 3rd or 4th entry or after a “no entry”. There was no time limit for number entry. Each subject was given six three item trials and three four item trials in which the items are particular double-digit integers.

Error categories are not mutually exclusive. For example, if the displayed items are 16 and 29, entries such as 19 and 26 can be errors in the ones digits or, reversing the two entries, errors in the tens digits; and if 19 had been displayed in an earlier set it could have been an “old” error.

To keep the errors as well defined as possible we limit our investigation to three item trials with single errors in each trial. Out of a total of 1146 three item trials, 19 trials included at least one “no entry”, 248 trials had a single errors, 90 had double errors and 13 of the trials had triple errors. We will focus on the 248 trials with a single error.

Descriptive statistics was calculated using SPSS Modeler and Excel. A simulation of random errors was performed using Excel.

***Sample.*** 193 Russian undergraduate students of the State University of Humanities and Social Studies (121 (63%) females and 71 (37%) males, mean age 18.8 years) participated in the study for extra credit. Each participant was tested individually in a quiet room. An experimenter was present throughout each session.

One student record was discarded — the student had only responded once out of a possible thirty times.

## Terms

The terms used in this article are as follows: the displayed *items* are *integers* made up of two *digits*, the subjects create *entries*. A *singlet* is the combination of a position and a digit and can be either a *ones digit* or a *tens digit*. A *trial* consists of 3 or 4 displayed items and the overall *order* of the items is the presentation order. If an item or an entry is divisible by N, N is a *factor*.

## Results

Our first finding is that the number of errors of just the tens (ones) digit is 41% (38%). A simulation of 12,000 entries in which the third entry was a random number between 21-99 had a much lower number of such errors — 9% (12%). Thus, test errors are much more likely than random numbers to consist of "singlet" errors.

We investigated whether numerical factors were under- or over-represented in the errors. The results are displayed in Fig. 1. Out of the factors 2, 3, 5, 7 and 11, only 5 and 11 were underrepresented.

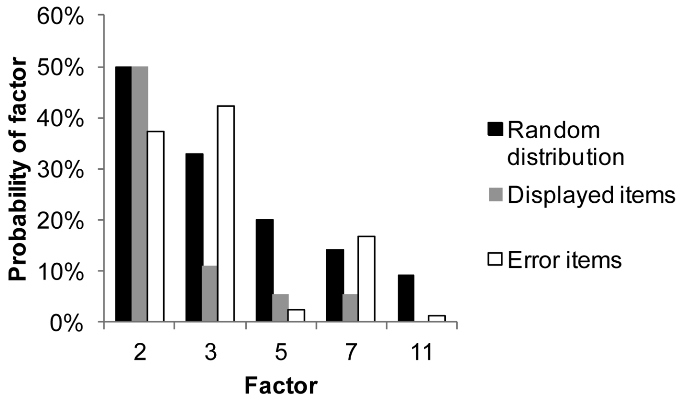


**Fig. 1.** Probability of an item (random distribution, displayed items and error items) being divisible by factors 2,3,5,7 or 11

## Discussion

The over-representation of tens and ones digit errors compared to chance shows that the two singlets form two relatively separate underlying structures which we can call maps. Errors occur separately within each map presumably because something can move within each map but much less likely between maps. The movement is done by what we call a pointer. Integers from the two maps are recalled together so there is a synchronization that allows pointers to point to at least two maps at the same time, we call this a *pointer* *collection*. The apparent structure is displayed in Fig. 2. Presumably there is a self-consistency relationship between pointers and maps that allows for chunking (Miller, 1956): many repeats of identical pointer collections may create a new map allowing the substitution of a single pointer for the pointer collection. Presumably, this self-consistency relationship also extends downwards: a digit may have originated in pointer collections of the geometric line combinations representing the digit.

From the tens and ones maps we infer the presence of multiple maps for each integer: these particular two maps may have originated in repeats of pointers to a map of double digit integers that stressed the function of the first digit and second. Other maps of the same integers may include a map of integers divisible by 11 and a map of integers divisible by 5 to explain the underrepresentation of these factors in the errors.

Finally, the errors come about because activated integers attract the pointers presumably via a positive feedback loop in which the feedback increases the activation level of the integers.

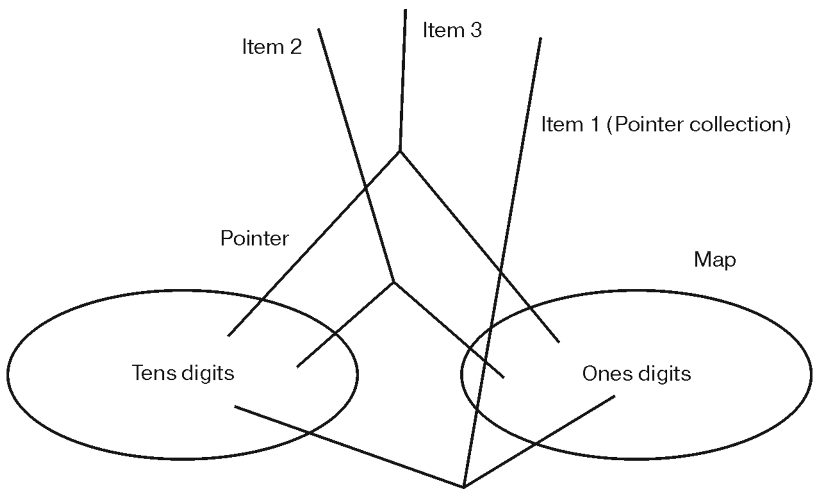


**Fig. 2.** Model of working memory using information from errors. Pointers point to digits within the tens or one digit maps and the pointer collections forms the integers items

What we have described is the structure of some kind of self-organizing map (see, for example, Kohonen & Hari, 1999; Dittenbach, Merkl & Rauber, 2000) with repeating pointers creating the self-organization.

This Ershova-Tarnow model allows us to define the relationship between working memory, short term memory and long term memory. The pointers make up working memory, the maps make up long term memory and short term memory is the partially activated parts of long term memory (Tarnow, 2008). Short term memory attracts the pointers, sometimes causing errors.

## General Discussion

We found that the overwhelming majority of errors originate separately in the tens and ones digits forming a base 10 representation. This information allowed us to infer the existence of a self-organizing system of pointers and maps. It also allowed us to conceptually define the difference between working memory, long term memory and short term memory: working memory correspond to the pointer collections, the maps correspond to long term memory and short term memory is activated long term memory which may cause the pointer errors.

The model connects with the literature as follows. Working memory capacity corresponds to the number of simultaneous pointer collections. Free recall has been found to include two parts (Tarnow, 2015b): the emptying of working memory (corresponding to the use of the current pointer collections) and reactivation of short term memory (positive feedback between a pointer collection and a set of maps). It is known that the latter process creates errors at a rate of about 1% per second (Tarnow, 2014). Recognition is quicker for items recently activated, corresponding to a quicker positive feedback process between a pointer and a short term memory (Tarnow, 2008).

Memory maps are found in the brain (O'Keefe, 1974, Pennfield's homunculus map). When an integer is read in, many memory maps should be activated corresponding to the separate steps making up the memory items (some of which are hierarchical) while if the same integer is internally recalled, fewer maps should be activated and empirically there is a difference between external and internal maps (Debaere et al, 2003). The creation of new maps from the pointer collections is similar to MacGregor's (1987) idea that working memory should have a limited capacity because it forces the chunking (the creation of new maps) resulting in more efficient retrieval. Note that our model has two scales in it rather than MacGregor's one: the number of pointer collections (which is the capacity of working memory) and the number of pointers in a pointer collection (which leads to chunking). The two scales are not necessarily the same. The creation of new maps may correspond to the workings of the pedagogy ladder of Vygotsky and the spiral pedagogy used in mathematics.

This new model is different from the Cowan et al (2014) model in which storage capacity is divided between central and peripheral storage. The pointer collections of our model, presumably centrally located, do not themselves contain any storage, only point to storage. They make up the basis of a center of attention which can be quickly changed from one pointer collection to another; rather than the center of attention contemplated by Cowan et al (2014) in which several objects are in the center of attention at any one time. Our model is not inconsistent with McElree's (2006) dichotomy of focus of attention and peripheral in which the periphery is not capacity limited. Oberauer et al (2012) finding that only one item at a time is in the focus of attention at any time suggests that one pointer collection is treated differently; this is not inconsistent with the Consciouness Pointer of Tarnow (2003) which is necessary to allow dreams to sample long term memories into a coherent story. This special pointer collection is similar to Marois (2013) central component consisting of residual similarity between items in different domains.

People who mix up number positions may have positional maps that do not separate well. This phenomenon should be further investigated since it may have to do with the fundamental ability to keep pointers in separate maps.

### Limitations

We have limited ourselves to analyzing only trials with three items with single errors, it could be that trials with multiple errors or with a different number of items would show evidence of a different memory architecture. More fundamentally, had we studied other items (listed in Cowan, 2014), a different structure may have emerged as well.

## REFERENCES

Alloway, T.P. & Gregory, D. (2013). The predictive ability of IQ and working memory scores in literacy in an adult population. *International Journal of Educational Research*, *57*, 51—56. doi: 10.1016/j.ijer.2012.10.004

Alloway, T.P. & Alloway, R.G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology*, *106*, 20—29. doi: 10.1016/j.jecp.2009.11.003

Allport, A. & Wylie, G. (1999). Task-switching: Positive and negative priming of task-set. In G.W. Humphreys, J. Duncan & A.M. Treisman (Eds.), *Attention, space and action: Studies in cognitive neuroscience* (pp. 107—132). Oxford: Oxford University Press. doi: 10.1016/S0010-0285(02)00520-0

Baddeley, A.D. (2001). Is working memory still working? *American Psychologist*, *56* (11), 851.

Baddeley, A.D. & Hitch, G. (1974). Working memory. *Psychology of learning and motivation*, *8*, 47—89. doi.org/10.1016/S0079-7421(08)60452-1

*Broadbent, D.E.* (1975). The magic number seven after fifteen years. In: Kennedy A., Wilkes A., editors. Studies in long term memory. Oxford, England: John Wiley & Sons; 1975. pp. 3—18. doi: 10.1002/bs.3830210208

Bull, R. & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental neuropsychology*, *19*(3), 273—293. doi: 10.1207/S15326942DN1903_3

Byrne, M.D. & Bovair, S. (1997). A working memory model of a common procedural error. *Cognitive science*, *21*(1), 31—61.

Conway, A.R., Kane, M.J., Bunting, M.F., Hambrick, D.Z., Wilhelm, O. & Engle, R.W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic bulletin & review*, *12*(5), 769—786. doi: 10.3758/BF03196772

Cowan, N., Saults, J.S. & Blume, C.L. (2014). Central and peripheral components of working memory storage. *Journal of Experimental Psychology: General*, *143*(5), 1806.

Cowan, N., Fristoe, N.M., Elliott, E.M., Brunner, R.P. & Saults, J.S. (2006). Scope of attention, control of attention, and intelligence in children and adults. *Memory & Cognition*, *34*(8), 1754—1768. doi: 10.3758/BF03195936

Cowan, N., Rouder, J.N., Blume, C.L. & Saults, J.S. (2012). Models of Verbal Working Memory Capacity: What Does It Take to Make Them Work? *Psychological Review*, *119*(3), 480—499.

Daneman, M. & Carpenter, P.A. (1980). Individual differences in working memory and reading. *Journal of verbal learning and verbal behavior*, *19*(4), 450—466. doi: 10.1016/S0022-5371(80)90312-6

Debaere, F., Wenderoth, N., Sunaert, S., Van Hecke, P. & Swinnen, S.P. (2003). Internal vs external generation of movements: differential neural pathways involved in bimanual coordination performed in the presence or absence of augmented visual feedback. *Neuroimage*, 19(3), 764—776. doi: 10.1016/S1053-8119(03)00148-4

De Lima Ferreira, T., Brites, C., Azoni, C.A.S. & Ciasca, S.M. (2015). Evaluation of Working Memory in Children with Attention Deficit/Hyperactivity Disorder. *Psychology*, 6(13), 1581. doi: 10.4236/psych.2015.613155

Dittenbach, M., Merkl, D. & Rauber, A. (2000, July). The Growing Hierarchical Self-Organizing Map. In *IJCNN* (6) (pp. 15—19). doi: 10.1016/S0925-2312(01)00655-5

Donald, M. (1991). *Origins of the modern mind: Three stages in the evolution of culture and cognition*. Harvard University Press. doi: 10.1002/ana.410320432

Engle, R.W. (2002). Working memory capacity as executive attention. *Current directions in psychological science*, *11*(1), 19—23. doi: 10.1111/1467-8721.00160

Engle, R.W., Tuholski, S.W., Laughlin, J.E. & Conway, A.R. (1999). Working memory, short-term memory, and general fluid intelligence: a latent-variable approach. *Journal of experimental psychology: General*, *128*(3), 309.

Ericsson, K.A. & Kintsch, W. (1995). Long-term working memory. *Psychological review*, *102*(2), 211.

Gathercole, S.E., Alloway, T.P., Willis, C. & Adams, A.M. (2006). Working memory in children with reading disabilities. *Journal of experimental child psychology*, *93*(3), 265—281. doi: 10.1016/j.jecp.2005.08.003

Henson, R.N., Norris, D.G., Page, M.P. & Baddeley, A.D. (1996). Unchained Memory: Error Patterns Rule out Chaining Models of Immediate Serial Recall. *The quarterly journal of experimental psychology*, *49*(1), 80—115. doi: 10.1080/713755612

Houdé, O. & Tzourio-Mazoyer, N. (2003). Neural foundations of logical and mathematical cognition. *Nature Reviews Neuroscience*, *4*(6), 507—514. doi: 10.1038/nrn1117

Kohonen, T. & Hari, R. (1999). Where the abstract feature maps of the brain might come from. *Trends in neurosciences,* 22(3), 135—139. doi: 10.1016/S0166-2236(98)01342-3

Luck, S.J. & Vogel, E.K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, *390*(6657), 279—281. doi: 10.1038/36846

Lynch, J.W., Kaplan, G.A. & Shema, S.J. (1997). Cumulative impact of sustained economic hardship on physical, cognitive, psychological, and social functioning. *New England Journal of Medicine*, *337*(26), 1889—1895. doi: 10.1056/NEJM199712253372606

MacGregor, J.N. (1987). Short-term memory capacity: Limitation or optimization? *Psychological Review*, *94*(1), 107.

Marois, R. (2013). The evolving substrates of working memory. Invited presentation to Attention & Performance XXV: Sensory Working Memory. Saint-Hippolyte, Québec; Canada: Jul, 2013. doi: 10.1016/B978-0-12-801371-7.09001-3

McElree, B. (2006). *Accessing recent events. Psychology of learning and motivation, 46,* 155—200. doi.org/10.1016/S0079-7421(06)46005-9

Miller, G. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. The psychological review, *63*, 81—97.

Moray, N. (1959). Attention in dichotic listening: Affective cues and the influence of instructions. *Quarterly journal of experimental psychology*, *11*(1), 56—60. doi: 10.1080/17470215908416289

Nation, K., Adams, J.W., Bowyer-Crane, C.A. & Snowling, M.J. (1999). Working memory deficits in poor comprehenders reflect underlying language impairments. *Journal of experimental child psychology*, *73*(2), 139—158. doi: 10.1006/jecp.1999.2498

Noble, K.G., McCandliss, B.D. & Farah, M.J. (2007). Socioeconomic gradients predict individual differences in neurocognitive abilities. *Developmental science*, *10* (4), 464—480. doi: 10.1111/j.1467-7687.2007.00600.x

O'Keefe, J. (1979). A review of the hippocampal place cells. *Progress in neurobiology*, 13(4), 419—439. doi: 10.1016/0301-0082(79)90005-4

Oberauer, K. & Hein, L. (2012). Attention to information in working memory. *Current Directions in Psychological Science*, 21, 164—169. doi: 10.1177/0963721412444727

Phillips, W.A. & Christie, D.F.M. (1977). Components of visual memory. *The Quarterly Journal of Experimental Psychology*, *29*(1), 117—133. doi: 10.1080/00335557743000080

Swanson, H.L. & Sáez, L. (2003). Memory difficulties in children and adults with learning disabilities. *Handbook of learning disabilities*, 182—198. doi: 10.1177/002221949402700107

Tarnow, E. (2003). How dreams and memory may be related. *Neuropsychoanalysis*, *5*(2), 177—182. doi: 10.1080/15294145.2003.10773424

Tarnow, E. (2008). Response probability and response time: a straight line, the Tagging/Retagging interpretation of short term memory, an operational definition of meaningfulness and short term memory time decay and search time. *Cognitive neurodynamics*, *2*(4), 347—353. doi: 10.1007/s11571-008-9056-y

Tarnow, E. (2013). *U.S. Patent Application No. 14/066,195.*

Tarnow, E. (2015a). Retrieval process in free recall creates errors in short term memory but not in long term memory. *Bulletin of the Peoples' Friendship University of Russia. Series: Psychology and Pedagogics*, *2*, 47—53.

Tarnow, E. (2015b). First direct evidence of two stages in free recall and three corresponding estimates of working memory capacity. *Bulletin of the Peoples' Friendship University of Russia. Series: Psychology and Pedagogics*, *4*, 15—26.



**Article history:**
*Received* 14 December 2016
*Accepted* 17 January 2017

**For citation:**
**Ershova R.V., Tarnow E. (2017). Working Memory Structure Revealed in Analysis of Recall Errors. *RUDN Journal of Psychology and Pedagogics*, 14 (1), 17—25.**

**Bio Note:**
*Regina V. Ershova* — Ph.D. in psychology, associate professor, professor of Psychology Chair of State University of Humanities and Social Studies (Kolomna, Russia). *Contact information:* e-mail: erchovareg@mail.ru

*Eugen Tarnow* — PhD, Data Scientist, Director of Consulting Avalon Business Systems (New York, USA). *Contact information:* e-mail: etarnow@avabiz.com

# ИЗУЧЕНИЕ СТРУКТУРЫ РАБОЧЕЙ ПАМЯТИ НА ОСНОВЕ АНАЛИЗА ОШИБОК В ЕЕ ФУНКЦИОНИРОВАНИИ

**Р.В. Ершова**

Государственный социально-гуманитарный университет
*ул. Зеленая, 30, Коломна, Россия, 140410*

**Ю. Тарноу**

Авалон Бизнес Системс, Инк.
*18-11 Редбурн Роад, Фейр Лоун, Нью-Джерси 07410, США*

В статье проведен анализ ошибок, происходящих в процессе выполнения теста рабочей памяти (TUT), направленного на припоминание представленных на дисплее двузначных чисел, у 193 студентов российского вуза.

Большинство ошибок в попытках, состоящих из трех двузначных чисел, — это ошибки в цифрах, указывающих на десятки или единицы. Это может свидетельствовать о том, что существуют отдельные карты памяти для десятков и единиц, а их объединение в целые числа осуществляется на основе неких указателей, составляющих набор. Количеством указателей в наборе возможно определяется объем рабочей памяти. Модель самоорганизующихся карт памяти функционирует на основе включения в карты памяти наборов общих для десятков и единиц указателей, в результате чего происходит замена наборов указателей единственным указателем. Поскольку среди ошибочных воспроизведений практически отсутствуют числа, кратные 5 и 11, можно предположить, что для чисел этого порядка существуют дополнительные карты памяти.

**Ключевые слова:** рабочая память, ошибки рабочей памяти, представленность целых в рабочей памяти, карта памяти, указатели

**История статьи:**
*Поступила в редакцию*: 18 декабря 2016
*Принята к печати*: 17 января 2017

**Для цитирования:**
**Ершова Р.В., Тарноу Ю. Изучение структуры рабочей памяти на основе анализа ошибок в ее функционировании // *Вестник РУДН. Серия: Психология и педагогика*. 2017. Т. 14. № 1. С. 17—25.**

**Сведения об авторах:**
*Ершова Регина Вячеславовна* — доктор психологических наук, профессор кафедры психологии Государственного социально-гуманитарного университета (Коломна, Россия). *Контактная информация:* e-mail: erchovareg@mail.ru

*Юджин Тарноу* — независимый исследователь, директор, Авалон Бизнес Системс, Инк (Нью-Йорк, США). *Контактная информация:* e-mail: etarnow@avabiz.com