# ABSTRACTS

## September, 20: Theoretical and methodological aspects of SSA

### Anatoly Zhigljavsky. *An introduction to SSA*

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This is an introductory talk. I will briefly describe the SSA methodology, several extensions of the basic version of the SSA, some links between the SSA and the subspace-based methods in signal processing. I also touch upon some history of SSA and mention some areas of application of SSA.

### Milan Palus. *SSA. Uncovering dynamics and interactions in complex systems*

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Beyond the standard variance-based Monte Carlo SSA tests, one can quantify dynamics of the SSA modes, or "Empirical Orthogonal Functions" (i.e., components of the SSA decomposition - filtering - projection of the studied data) so that dynamical modes are identified which are more regular, or better predictable than linearly filtered noise [1, 2]. Instantaneous phases of oscillatory SSA modes [3] can be used in phase synchronization or phase coherence analysis [4] aimed at uncovering complex cooperative phenomena when oscillations with similar periods exist in different processes, e.g. in solar/geomagnetic activity and climate variability [5, 6]. Inferring nonlinear phenomena, however, nonlinearity in the mode dynamics should be quantitatively assessed [7, 8]. Existence of directed interactions or causal relations can also be tested [9]. Sophisticated surrogate data/bootstrap techniques should be used in order to detect oscillatory and/or synchronization phenomena in complex, possibly multiscale processes [10].

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**Nina Golyandina.** ***On the choice of parameters in Singular Spectrum Analysis and related sub space-based methods***

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We investigate methods related to both the Singular Spectrum Analysis (SSA) and subspace-based methods in signal processing. We describe common and specific features of these methods and consider different kinds of problems solved by them such as signal reconstruction, forecasting and parameter estimation. General recommendations on the choice of parameters to obtain minimal errors are provided. We demonstrate that the optimal choice depends on the particular problem. For the basic model `signal + residual' we show that the error behaviour depends on the type of residuals, deterministic or stochastic, and whether the noise is white or red. The structure of errors and the convergence rate are also discussed. The analysis is based on known theoretical results and extensive computer simulations.

**Donald Poskitt and Md Atikur Rahman Khan.** ***A Conditional Moment Test for Window--Length Selection in Singular Spectrum Analysis of Regular Processes***

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The dimension of the trajectory matrix in Singular Spectrum Analysis is governed by the, so called, window--length (or window--size) parameter. The selection of the window--length, which must be assigned by the practitioner, is therefore very important as, in the light of known embedding properties, this choice can clearly critically affect the signal extraction and reconstruction features of the analysis. Assuming that certain regularity conditions are supported by the data, this paper proposes a conditional moment test as a tool for selecting the window length of the trajectory matrix. A Portmanteau type version of the test is also considered. The rationale behind the procedure is to search for a window--length such that there is little or no dependence between observations separated by a time period that exceeds the window--length. Simulation results and practical examples are used to illustrate the usefulness of the method for various processes, including long memory process and non--stationary time series.

**Ivan Markovsky.** ***Fitting algebraic curves to data***

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An algebraic curve is a solution set of a system of polynomial equations with dimension one. Conic sections, for example, are algebraic curves in a two dimensional space, obtained as a solution set of a second order polynomial equation. Fitting of conic section and more specifically ellipses to data has long history. The methods can be classified as geometric and algebraic, depending on the fitting criterion. In this talk, we show that geometric fitting of conic sections is equivalent to a second order nonlinearly structured low-rank approximation and algebraic fitting can be viewed as a relaxation of the nonlinarly structured problem to a linear one. More generally, algebraic curve fitting to data is a polynomially structured low-rank approximation. The result leads to conceptual unification of curve fitting methods as well as a practical benefit of using a single algorithm and a piece of software for solving a wide range of curve fitting problems.

**Konstantin Usevich.** ***Singular Spectrum Analysis for textured images***

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In this talk we discuss the applicability of SSA to analysis of images with texture. The following important problems are under investigation: segmentation, classification and defect detection in textured images. A review of earlier SSA-like approaches is presented. New methods arising from Singular Spectrum Analysis are proposed.

**Jonathan Gillard.** ***Singular spectrum analysis, Cadzow iterations, and linear recurrent formulae***

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As an approximation to a Hankel trajectory matrix $X$, singular spectrum analysis (SSA) yields a Hankel matrix $\tilde{X}$. This matrix is obtained as a result of the diagonal averaging of a matrix of rank $r$ obtained through the singular value decomposition of $X$. Hence $\tilde{X}$ is typically a matrix of full rank. In signal processing applications however, a parametric form of an approximation is typically of prime importance, and hence one may wish to find a Hankel matrix of rank $r$ which gives the best approximation to $X$; this is a problem known as structured low-rank approximation.
Given a structured matrix $X$ (in our context, Hankel), some norm $\|\cdot\|$, and an integer $r$, the structured low rank approximation problem is as follows:

$$\min_{\hat{X}} \|X - \hat{X}\| \text{ subject to } \begin{cases} rank(\hat{X}) \leq r, \\ \hat{X} \text{ has the same structure as } X. \end{cases}$$

If the $L_2$ norm is selected, then this is known as the structured total least squares problem, an extension of the total least squares problem.
The simplest procedure of finding a solution to structured total least squares problem (but not necessarily the globally optimal solution) is the so-called Cadzow iterations which are the repeated alternating projections of the matrices (starting at $X$) to the set of matrices of rank $r$ (by performing the SVDs) and to the set of Hankel matrices (by making the diagonal averaging). That is, Cadzow iterations are simply repeat iterations of SSA. This method has been shown to be suboptimal in terms of an L2 optimality criterion in some trivial examples. It is nevertheless a simple method that is readily implemented. Additionally there has been some recent evidence to suggest that Cadzow's algorithm outperforms some methods in reconstructing a noisy signal. Little has been done on the use of this method for forecasting.
This talk will detail the advantages and disadvantages of applying Cadzow iterations in constructing linear recurrent formulae, and the impact upon forecasting. A practical example will highlight the results.

### Karl Michael Schmidt and Valentina Moskvina. *Approximate Projectors in Singular Spectrum Analysis*

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This talk presents an approach to SSA using an effective and numerically stable high-degree polynomial approximation of a spectral projector, which also provides a means of time-series forecasting. Reconstructions based on low-eigenvalue components of the covariance matrix can be computed directly from the trajectory matrix, without calculating eigenvalues or eigenvectors. Using polynomials of lower degree provides an approach to fuzzy SSA.

### Andrey Pepelyshev. *Comparison of vector and recurrent forecasting*

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There are two main forecasting procedures in SSA. The recurrent forecast is based on an iterative application of the estimated linear recurrent formula to the reconstructed time series. The vector forecast is based on an extension of the matrix corresponding to chosen eigentriples by iterative adding columns lying in the same subspace and the subsequent diagonal averaging of the extended matrix. In my talk I will compare these forecasting procedures by a number of examples.

## September 21: Applications of SSA in economics and finance

### Hossein Hassani. *A Review on Singular Spectrum Analysis for Economic and Financial Time series*

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In recent years Singular Spectrum Analysis (SSA), a relatively novel but powerful technique in time series analysis, has been developed and applied to many practical problems across different fields. In this talk I review recent developments in the theoretical and methodological aspects of the SSA from the perspective of analyzing and forecasting economic and financial time series, and also represent some new results.

**Saeid Heravi.** ***Forecasting UK Industrial Production with Multivariate Singular Spectrum Analysis***
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In recent years the Singular Spectrum Analysis (SSA) technique has been further developed and applied to many practical problems. The aim of this research is to extend and apply the SSA method, using the UK Industrial Production series. The performance of the SSA and multivariate SSA (MSSA) techniques assessed by applying it to eight series measuring the monthly seasonally unadjusted industrial production for the main sectors of the UK economy. The results are compared with those obtained using the ARIMA and VAR models. We also develop the concept of casual relationship between two time series based on the SSA techniques. We introduce several criteria which characterize this causality. The criteria and tests are based on the forecasting accuracy and the predictability of the direction of change. The proposed tests are then applied and examined using the UK industrial production series.

**Christina Beneki and Costas Leon.** ***Singular Spectrum and Cross-Spectral Analysis of the USA GDP and Unemployment Time Series***
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We apply univariate SSA on USA GDP and unemployment seasonally adjusted quarterly time series for the period 1948:1-2010:2. By means of SSA we first filter out the stochastic trend of both time series and then focus on the extraction of cycles. In turn, we employ the obtained from the SSA cyclical signals in cross-spectral analysis. The cycles are characterized by a relatively high coherency in the typical business cycle spectrum. We also examine the synchronization of the two cyclical signals by means of the phase spectrum and we conclude that GDP is a leading indicator of unemployment. Measures of coherency and synchronization across different bands of the business cycle spectrum are also presented. These results are robust to various window lengths in the SSA stage and also to different window functions in the cross-spectral analysis.

**Andreia Dionisio and Rui Menezes.** ***On the Globalization of the Stock Market: An Application of Granger Causality, Mutual Information and SSA to the G7***
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This paper analyzes the process of stock market globalization on the basis of three different approaches: Granger causality tests, mutual information tests and SSA techniques. While the Granger causality tests are based on regression models and typically capture linearities in the data, mutual information is well suited for capturing global non-parametric relationships in the data without imposing any structure or restriction on the model. The data used in our empirical analysis were drawn from DataStream and comprise the natural logarithms of relative stock market indexes since 1973 for the G7 countries. The main results point to the conclusion that significant causal effects occur in this context and that mutual information, the global correlation coefficient and the SSA technique actually provide more information on this process than Granger causality tests, but the direction of causality is difficult to distinguish in the former case. In both cases however there is evidence that stock markets are closely related in the long-run over the 36 years analyzed and, in this sense, one may say that they are globalized.

**Jiawei Zhang and Shouyang Wang.** ***A study on China's business cycle based on SSA***
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Singular spectrum analysis is a newly developed tool for modeling time series and extracting signals, and has found its great applications in many fields such as economics, physics and so on. However, literature investigating the business cycle based on SSA is still not available. In this paper, we for the first time attempt to study Chinese business cycle using this new methodology.
Business cycle monitoring mainly consists of two steps: extraction and reconstruction. For the extraction, the original time series must be filtered since they are usually contaminated by seasonal patterns and noise which make it difficult to distinguish cycle pattern from other patterns. With regard to the reconstruction, indexes used to monitor business cycle are then reconstructed based on the

business cycle signals extracted from the original series. Under the traditional framework, it is difficult to combine extraction and reconstruction together since these two steps are separated from each other. However, the SSA method makes such combination possible.

This work is presented in two parts. In the first part, we use one-dimension time series SSA to extract the cycles from the original data and then reconstruct it using OECD method. In this part, we aim at comparing the SSA with other method like X12-ARIMA to see which method is more powerful in signal-extracting. In the second part, we use multi-dimension time series SSA to extract the cycles and then reconstruct the leading and composite index directly. Finally, these indexes are also compared with the relevant result by OECD construction method to see whether or not the related leading indicator system via SSA is more precise and efficient.

### **Abdol Soofi.** ***Applications of SSA and MSSA in Economics and Finance***

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The proposed presentation aims to report the results of a novel application of singular spectrum analysis to financial data. We use univariate and multivariate singular spectrum analysis for predicting the value and the direction of changes in the daily pound/dollar exchange rate. To perform the forecast, we also use the daily dollar exchange rates with respect to Euro. We use the random walk model as a benchmark model to evaluate performances of the singular spectrum analysis as a prediction method. The empirical results show that the forecast based on the multivariate singular spectrum analysis compares favourably to the forecast of the random walk model, both for predicting the value and the direction of changes in the daily pound /dollar exchange rate. This result is validated by the use of Diebold-Mariano test statistics that enabled us to rule out the comparative results are chance occurrences. We compare the predictions based on an error correction model (VAR model) with predictions based a random walk as well as prediction based on the MSSA. The superiority of the MSSA method is confirmed with respect to the performance of the VAR modelling. The results show that the random walk model outperforms the VAR model also.

### **Martin Kapl and Werner Mueller.** ***Prediction of Steel Prices: a Comparison between a Convential Regression Model and MSSA***

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In the presentation paper we compare two forecast procedures by its capabilities to predict market steel prices. One is based on the classical Box-Jenkins ARIMA class, the other on multi-channel singular spectrum analysis (MSSA). We find the two approaches competitive with an advantage for MSSA to be expected as the time series grow longer.

### **Paulo Ferreira.** ***Long-range correlations for stock indexes***

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One of the most important issues on financial markets is the existence or not of dependence in financial series. The analysis of dependence is one way to study the efficient market hypothesis and is important to analyse if there exist some capacity to predict in financial markets. In this study we use several different methods to analyse dependence in stock indexes such as linearity tests, mutual information and detrended fluctuation analysis. We study the G7 markets and also Greece, Portugal and Spain, since 1990 to 2010.

### **Saeid Sanei, Mansi Ghodsi, Foad Ghaderi.** ***Signal Separation, Extraction, and Restoration from Single Channel Signals by SSA; Applications to Biomedical Data***

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SSA decomposes the original time series into orthogonal components which typically represent oscillations, trends, and noise of the signal. The decomposition is used to analyze the structure of the time series and to extract the component(s) of interest (e.g. the signal without noise). SSA may be used in both decomposition and forecasting, since various signal components introduce different trends/behaviours in the SSA subspace/orthogonal bases.

Singular spectrum analysis may be used in signal source separation, extraction, and restoration from single channel data. This requires imposing some intelligence into the process to define the component of interest. Such an a priori may be known if the desired signal components can be characterised statistically. In biomedical applications such information can often be bio-inspired. Compared with other subspace algorithms, SSA can efficiently and more effectively decompose the

mixed signals into meaningful components representing the constituent source signals. A recursive reconstruction is then employed to identify the contributing subspaces and manipulate the corresponding subspace signals to reconstruct the desired signals.

The above concept can be exploited in processing of many biomedical multiple component data. Examples of such data are temporomandibular joint movement, heart and lung sounds, heart sound with murmur, and localization of sound components. It can also be seen that SSA can involve in generating proper reference signals for adaptive filters. This can lead to the design of cascaded adaptive filters.

# September 22: Applications of SSA in other areas

## Alain de Cheveigné. *SSA-based multichannel signal analysis and denoising*

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I will present two techniques related to SSA that are extremely effective for improving the signal-to-noise ratio of multichannel data such as from magnetoencephalography (MEG). The first technique uses estimates of the noise measured by reference sensors to regress the noise out of the brain channels. Augmenting the reference signals by time-shifted versions of the same allows the algorithm to synthesize finite impulse response filters (FIR) that compensate for convolutional mismatches, thus greatly improving the quality of the denoised data. The second technique extends component analysis techniques (e.g. PCA or ICA) that form linear combinations of sensor signals to obtain components representing noise, brain signals, etc. Augmenting the data array by time shifts allows the analysis to synthesize multichannel FIR filters, thus improving the separability of the data. In effect, this allows separation of components that are spatially colinear (and thus not separable by standard component analysis), but not jointly spatially and spectrally colinear. Again, the new technique provides a significant improvement in data quality.

## Irene L Hudson. *Three case studies: SSA in health environmetrics and in phenological climate change research*

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This paper reviews the use of singular spectrum analysis (SSA) (Golyandina *et al.* 2001) and the SSA change point (CP) detection method (Moskvina & Zhigljavsky 2003) in three recently published studies; one in health environmetrics (Hudson et al. 2005) and two in climate change phenological research (Hudson & Keatley 2010a, MacGillivray et al. 2010); the latter two detailed in the recent climate change book by Hudson & Keatley (2010b). The major aim of Hudson et al. (2005) was to investigate the value of SSA in modelling climate effects on sudden infant deaths (SIDS) in NZ. SSA showed significant current and lagged impacts of climate, identified seasonal and cyclic trends, and change points in the SIDS time series. All climate variables were shown to impact on SIDS, contemporaneously or within 1-3 months earlier. Rainfall, relative humidity and wind direction were highly *positively* correlated with SIDS, with a significant non-protective effect of increased rainfall and relative humidity (current to lag -3 months) and of changing wind direction from east to west, (at lag 0) in the given SIDS death month. Cross-correlation analysis of the major sub-component of the SIDS and of all the climatic series, showed that wind speed, dewpoint, temperature, and sunshine were highly *negatively* correlated with SIDS – thus significant *protective* effects on SIDS of increased temperature (lag 0 to -2); wind speed and radiation (lag 0 to -3 months). The least dominant SSA sub-structures confirmed that: (i) differential climate effects on SIDS (above seasonality) operated across wet/dry epochs, defined by ENSO; (ii) increased wind speed significantly increased SIDS risk in hot epochs, opposite to the negative effect of increased wind speed on lowering pollution. The first phenological study (Hudson & Keatley 2010) investigated SSA in modelling a 32 year flowering record of four Australian eucalypt species in relation to climate. SSA identified a trend, annual and biennial cycle in certain species. SSA was shown to offer ways to: [1] identify spatial and climate niche across species; [2] decompose time series into sub components (e.g. trends, oscillatory modes or seasonality, change-points and noise); [3] establish whether a given species is uniquely influenced by climate through the year (i.e. has its own climatic signature); [4] determine the relationship between multiple

climate indicators; [5] identify change points in the flowering; and [6] identify the primary climatic drivers of flowering or of any phenophase. Shifts in phenology (flowering, bird migration etc) due to climate change will have major impacts on biological systems. Though it has been appreciated that these CPs cannot be detected satisfactorily by either regression or correlation methods, these methods continue to be used in phenology. New techniques for CP analysis, enabling a representation of non-linear phenological responses and abrupt rates of change are needed (Hudson & Keatley 2010b). In the third study, a SSA CP study of Australian herbarium orchid records (MacGillivray et al. 2010), showed significant change points of increased decline in number of days to peak flowering near the end of the 20th century, i.e. 1995 and 1999/2000; agreeing with trends shown by the Bayesian CP methods of Dose & Menzel (2004). Analysis of change incorporating temperature is a topic of further investigation.

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## Valentina Moskvina. *Signal processing in genome-wide association studies*

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Genome wide association studies (GWAS) have been highly successful in identifying many new genes involved in the pathogenesis of complex disorders. The problems emerging from such studies are the population (or other) admixture in the samples and the high rate of false-positive results due to technical artefacts. Some of these problems can be identified and addressed using standard quality control characteristics but conceivably some false positive significant results can escape such filtering procedures. Similarly, many genuine positive results could also be missed, as they do not reach genome-wide significance due to small effect sizes.

In this work we present the association results of different GWAS as time series and discuss possible application of SSA techniques to these time series. The natural order of markers - singular nucleotide polymorphisms (SNPs) - physical position, and the correlation between them provide additional information to the individual significance for each marker reinforcing the signal when there is a true association. In contrast, when we observe significant results either occurred by chance or caused by experimental error, a single significant marker appears on the background of many insignificant markers within a correlation block. We try to identify the regions in the human genome associated with psychiatric and neurological disorders using SSA. This methodology allows firstly, detecting genetic association with the disease taking into account significance of several subsequent genetic markers, and secondly, it may detect the genetic association with the disease taking into account underlying structure of the genome.

## Elias Dana. *The use of Singular Spectrum Analyses for managing invasive species*

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Ecological systems are characterised by complex multi-dimensional interactions. These include inter-specific, intra specific and biological responses at different sub-levels (physiological, reproductive or

behaviour changes, food-webs, etc.), which are generally influenced by environmental properties and their changes, some of the latter being periodical and some others, no-easily predictable variations.
Biological populations and their communities are extremely difficult to model through time due to these uncontrollable sources of variation.
However, analysing and predicting biological changes at population level are essential for Biodiversity Conservation. In the general cases, population patterns are difficult to analyse through conventional methods of life-tables: intensive surveying and monitoring are required and long time series are difficult to obtain, the studies generally accounting for 3-5 years of field sampling in one (or a few) subjectively selected sites of study. These difficulties make the final results of limited utility for management in practice.
Management of Biodiversity usually faces three sub-disciplines: species management and community or habitats managements, and more rarely, ecological processes. This implies another problem that is not usually present in pure ecological studies: the effect of management on population trends and processes. For instance, management interact with processes related to size and density dependent processes, introduction of biases in sex-ratios, changes in behaviour or feeding preferences. Managing Biological Invasions is a field of work that feeds from existing science-based information on ecological and biological process and from accumulated experience on how to deal with invasive (non-native and spreading) species. The analyses most often required consist in: 1) knowing how population numbers and cohorts vary through time with management actions and 2) forecasting the future trend of the population managed. This information is of great importance for a number of purposes such as planning of resource allocation, prediction of population increase above minimum desired level, identification of optimal periods for temporally increasing control efforts, etc. The vast majority of invasive species are characterised by their ability to rapidly response to slight environmental changes (fastening fruit maturation, changing feeding preferences, moving to other habitats, etc.). Within these circumstances analytical methodologies are difficult to conduct.
Singular Spectrum Analysis may represent a good alternative for rapidly inspecting and forecasting time series of biological populations. However, as is demonstrated in this talk, it has been poorly used in ecological sciences, and, to our knowledge, never employed within Management of Invasive Species. A search in ISI- Thomson Reuters database by using the terms ‘singular spectrum analysis only gave 998 references. Near 23% (230) of them had been published in specialised journals on Mathematical sciences, 21.04% (210) had been published in Physics, 17,33% (173 references) in Engineering journals, 17,33% (173) in journals belonging to Meteorology & Atmospheric Sciences, being the remaining references mainly concentred in other journals not related to ecological aspects (Geology, 126; Computer Science, 114; Chemistry, 106; Biochemistry & Molecular Biology, 93; Astronomy & Astrophysics, 72). Only a small amount of references reporting the use of SSA for their studies was found in journals of Environmental Sciences & Ecology (35), Zoology (12) and Diversity and Conservation (2). However, when these articles were inspected, none of them deal with studies at species or population level.
Some reasons for this lack of implementation within ecological sciences and wildlife management are commented and solutions are provided to correct this undesirable bias of knowledge implementation.

## Haibin Xie and Shouyang Wang. *Iteration-based SSA forecasting: An application to Chinese GDP*

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In this paper, based on the iteration scheme the singular spectrum analysis (SSA) is applied to forecasting the Chinese GDP. The results indicate the feasibility of such scheme and the dominance of SSA over ARIMA model. Moreover, consistent with results of Hassani, Heravi, and Zhigljavsky (2009), our empirical results also demonstrate that the SSA model is more powerful at longer horizon forecasts.