

Claruscuro N° 20 (Vol. 2) - 2021

Revista del Centro de Estudios sobre Diversidad Cultural

Facultad de Humanidades y Artes

Universidad Nacional de Rosario

Rosario – Argentina

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Title: A Simulation-Based View on Mesopotamian Computational Practices

Título: Las prácticas mesopotámicas de computo, una mirada basada en simulaciones

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Fuente: Claruscuro, Año 20, N° 20 (Vol. 2) - Diciembre 2021, pp. 1-14.

DOI: 10.35305/cl.vi20.66

Publicado en: <https://claruscuro.unr.edu.ar/>



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ISSN 2314-0542 (en línea)

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A Simulation-Based View on Mesopotamian Computational Practices

*Mathieu Ossendrijver**

Abstract

It is argued that iterative computations which are attested in Mesopotamian and other ancient sources can be productively analyzed and interpreted in a simulation-based framework. Ancient Mesopotamia presents us with a rich body of textual evidence for computational practices over a period of more than three millennia. This paper is concerned with Mesopotamian iterative computations of empirical phenomena, where each iteration updates the values of certain quantities from one state to the next state. It will be argued that these computations can be fruitfully interpreted in the so-called simulation-based framework, which was recently developed by philosophers of science in order to better account for the role of simulations in modern science. This is exemplified on the basis of a text from the Ur III period (2100–2000 BCE) about the growth of a cow herd. Other Mesopotamian sources with iteratively computed sequences, in particular various types of mathematical tables, are ignored here, because they do not directly correspond to any phenomena. Section 1 briefly addresses some developments in the philosophy and historiography of science in order to introduce the simulation-based framework. Section 2 discusses the textual example. Section 3 contains the conclusions.

Key-words: Mesopotamia; computing; simulation; models; herd growth.

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Recibido: 30/09/2021, Aceptado: 14/10/2021

Las prácticas mesopotámicas de computo, una mirada basada en simulaciones

Resumen

Se discute que los cálculos iterativos que se atestiguan en las fuentes mesopotámicas y otras fuentes antiguas pueden analizarse e interpretarse de forma productiva en un marco basado en la simulación. La antigua Mesopotamia nos presenta un rico cuerpo de evidencia textual de prácticas computacionales durante un período de más de tres milenios. Este artículo se ocupa de los cálculos iterativos mesopotámicos de fenómenos empíricos, en los que cada iteración actualiza los valores de ciertas cantidades de un estado al siguiente. Se argumentará que estos cálculos pueden ser interpretados de manera fructífera en el llamado marco basado en la simulación, que fue desarrollado recientemente por los filósofos de la ciencia con el fin de explicar mejor el papel de las simulaciones en la ciencia moderna. Esto se ejemplifica a partir de un texto del periodo Ur III (2100-2000 a.C.) sobre el crecimiento de un rebaño de vacas. Otras fuentes mesopotámicas con secuencias calculadas de forma iterativa, en particular varios tipos de tablas matemáticas, se ignoran aquí, porque no se corresponden directamente con ningún fenómeno. La primera sección aborda brevemente algunos desarrollos en la filosofía y la historiografía de la ciencia para introducir el marco basado en la simulación. La segunda sección analiza el ejemplo textual. La última sección contiene las conclusiones.

Palabras clave: Mesopotamia; cómputo, simulación; modelos; aumento de rebaño

1 A simulation-based view on iterative computations

In¹ scientific contexts, simulation usually denotes an iterative computation performed on a computer. In many fields of science and engineering, such as astrophysics, climate research, chemistry, biology, and aerodynamics, but

¹The ideas and the example which are discussed in this paper were first presented at the Freie Universität Berlin, Fachbereich Geschichts- und Kulturwissenschaften, 16 April 2021.

also in the humanities, computer simulation has become a very important, sometimes the only available means to investigate, explain, or predict empirical phenomena. Due to the steady increase of computational power, simulations are able to “solve” increasingly complex systems of equations. In the wake of these developments, philosophers of science discovered simulation as a topic worthy of reflection in the 1990s. The framework in which this reflection took shape is the model-based or semantic view on knowledge production. According to this view, models, in the sense of idealized systems specified by theories, are the central tools of scientific practice. The model-based or semantic view emerged in the 1960s, when philosophers of science realized that it provides a better account of actual scientific practice than the so-called syntactic view on knowledge production, which operates with axiomatic systems (Suppe 1974, 1989; Bailer-Jones 2009: 126–158). According to the syntactic view, which was developed by logical empiricists such as Carnap and Hempel and can be traced back to Aristotle, language is the fundamental mode of expression for scientific knowledge. In this view scientific theories are, ideally, systems of statements which are deduced from fundamental assumptions, also known as axioms, by means of logic (Bailer-Jones 2009: 84–142). The seminal classical example of an axiomatic system is Euclid’s mathematical treatise *Elements* (ca. 300 BCE). In reality, science does not operate only with language-based axiomatic systems, but with models of various kinds, e.g. mathematical or mechanical, to draw inferences about phenomena. In the model-based view scientific practice is understood in terms of constructing and reasoning with models and idealized phenomena (Freudenthal 1961; Magnani and Nersessian 2002; Bailer-Jones 2002, 2009; Nersessian 2008). That is, scientific models are concerned with idealized phenomena rather than actual phenomena. Real phenomena can nevertheless be studied and explained in this manner, provided that the model system corresponds with the real system to a sufficient degree (Craver 2002: 65).

Simulations are distinguished from other kinds of models mainly by their dynamical nature and their iterative method of computation. The role of simulations in scientific practice is understood similarly to that of other models, that is, scientists perform simulations in the hope that their dynamical behavior is sufficiently similar to that of real systems, so that the former can be studied to learn something about the latter (Winsberg 2009: 836). However, the complexity that is typical for many simulations

raises new philosophical questions (Winsberg 1999; 2009)². For the present purpose it suffices to mention the question of how theories can be justified. In an ideal situation this is assured in two distinct steps, namely validation and verification. Validation assures that the theory underlying the model correctly represents the empirical phenomena, while verification assures that the model reproduces the theory sufficiently accurately (Winsberg 2009). This distinction is difficult to maintain for simulations, because the theories on which they are based are approximated, idealized, discretized, and supplemented with parametrizations, initial values, boundary conditions, etc. Each of these manipulations affects the outcome of the simulation, but often only their cumulative effect can be compared with empirical data. Validation and verification therefore merge in one inseparable process of justification. As a consequence, a simulation that is judged to be correct may involve a ‘balance of approximations’, which means that certain model parameters or approximations are tweaked, not to better model a particular phenomenon, but to counterbalance the effects of other approximations (Winsberg 2009: 839). This aspect of modern simulations will prove to be useful for understanding ancient simulations.

2 Mesopotamian case study: growth of an Ur III cow herd

Francesca Rochberg (2016: 252; 2018) was the first to apply a model-based analysis to Mesopotamian scholarly practices. During the second half of the first millennium BCE, Babylonian astronomers used a variety of mathematical models to represent, predict, and understand lunar and planetary phenomena. The nature of the models of Babylonian mathematical astronomy and their use by the ancient scholars is well captured by the model-based view (Rochberg 2016: 252; 2018: 139). The present investigation takes up her initiative to explore how the simulation-based view may lead to a better understanding of Mesopotamian iterative computations. Furthermore, cultural historians have identified iteration, understood in a much broader sense than in the present paper,

²See also Humphreys 2009 and other contributions in the special issues *Synthese* 169.3 (2009), “Models and Simulations”, Frigg, Hartmann and Imbert (eds.), *Synthese* 180.1 (2011), “Models and Simulations 2”, Frigg, Hartmann and Imbert (eds.), *Synthese* 190.2 (2013), “Models and Simulations 4”, Pincock and Vorms (eds.), and *Science in Context* 12.2 (1999), “Models, Simulations, and Their Objects”, Sismondo (ed.).

as a crucial cultural technique of ancient societies (Cancik-Kirschbaum and Traninger 2015). Babylonian mathematical astronomy would again be a most promising test case, since its main products are time-dependent model sequences of lunar and planetary phenomena. However, for the present purpose a less obvious and more ancient Mesopotamian example was selected.

AO 5499 is a Sumerian record from the Ur III period (ca. 2100–2000 BCE) about the growth of a cow herd and the amounts of butter oil and cheese produced by the herd. The tablet was acquired by the Louvre in 1910 and probably originates from the site of Drehem, ancient Puzriš-Dagan, which was an important economic center of the Ur III state. A hand copy was published in de Genouillac 1911: Plates XIII–XIV. The first edition by Ignaz Gelb appeared in 1967. Subsequently Vaiman 1971 published a detailed and groundbreaking analysis of the tablet³. The tablet was also discussed by Nissen, Damerow and Englund (1993), and Englund (1995). A complete translation is available on the CDLI website (Englund 2017).

Obverse and reverse are each divided into three columns separated by rulings, resulting in six columns of text (i–vi). The main text consists of ten annual lists, which occupy columns i–iv and the top part of column v. Each list ends with a year formula and is separated from the next one by an empty space. The final column (vi) contains the sum totals of the ten lists and a colophon mentioning the name of the scribe. For the present purpose it suffices to reproduce translations of the first four lists, which cover years 39–42 of king Šulgi⁴. For the remaining data, which are represented analogously on the tablet, see Table 1.

AO 5499 (CDLI No. P131589)

- Obv i 1) [4 mature cows]
- 2) [1 heifer calf, suckling]
- 3) [1 bull calf, suckling]
- 4) [Butter oil thereof:] 2 ban₂
- 5) [Cheese thereof:] 3 ban₂
- 6) Year “The household Puzriš-Dagan was erected” (Šulgi year 39)

³No English or German translation of Vaiman 1971 has been published, unlike several of his Russian papers on archaic cuneiform and Mesopotamian metrology, which were translated into German in *Baghdader Mitteilungen* 20 (1989) and 21 (1990).

⁴For the complete translation see Englund 2017.

- 7) 4 mature cows
- 8) 1 heifer, 1 year
- 9) 1 heifer calf, suckling
- 10) 1 bull, 1 year
- 11) 1 bull calf, suckling
- 12) Butter oil thereof: 2 ban₂
- 13) Cheese thereof: 3 ban₂
- 14) Year after “The household Puzriš-Dagan was erected” (Šulgi year 40)

- 15) 4 mature cows
- 16) 1 heifer, 2 years
- 17) 1 heifer, 1 year
- 18) 1 heifer calf, suckling
- 19) 1 bull, 2 year
- 20) 1 bull, 1 year
- 21) 1 bull calf, suckling
- 22) Butter oil thereof: 2 ban₂
- 23) Cheese thereof: 3 ban₂
- 24) Year after “The household Puzriš-Dagan was erected”, year after that (Šulgi year 41)

- ii 1) [4] mature cows
- 2) [1] heifer, 3 years
- 3) [1] heifer, 2 years
- 4) 1 heifer, 1 year
- 5) 1 heifer calf, suckling
- 6) 1 bull, 3 year
- 7) 1 bull, 2 year
- 8) 1 bull, 1 year
- 9) 1 bull calf, suckling
- 10) Butter oil thereof: 2 ban₂
- 11) Cheese thereof: 3 ban₂
- 12) Year “Šašru was destroyed” (Šulgi year 42)

Each annual list records the number of cows and bulls specified by age and the amounts of butter oil and cheese produced during that year. Ages are specified with the values suckling, 1 year, 2 years, 3 years, and mature. The amounts of butter oil and cheese are expressed in the capacity units of the Ur III period, where 1 gur = 5 barig, 1 barig = 6 ban₂, and 1 ban₂ = 10

year	butter oil	cheese	cows					bulls				
	ban ₂	ban ₂	mature	3 yr	2 yr	1 yr	calf	calf	1 yr	2 yr	3 yr	mature
39	2	3	4				1	1				
40	2	3	4			1	1	1	1			
41	2	3	4		1	1	1	1	1	1		
42	2	3	4	1	1	1	1	1	1	1	1	
43	2	3	5	1	1	1	1	1	1	1	1	1
44	2 1/2	3 3/4	6	1	1	1	1	2	1	1	1	2
45	3	4 1/2	7	1	1	1	2	1	2	1	1	3
46	3 1/2	4 3/4*	8	1	1	2	1	2	1	2	1	4
47	4	6	9	1	2	1	2	2	2	1	2	5
48	4 1/2	6 3/4	10	2	1	2	3	2	2	2	1	7
total	27 1/2	41 1/4										

Table 1: Tabular representation of the data in AO 5499 (based on Vaiman 1971, 50: Fig. 2, and Nissen, Damerow and Englund 1993, 101: Fig. 78).

sil₃ (1 sil₃ ≈ 1 liter). The animals are listed systematically, with the cows first and the bulls in second position, and for each gender from mature down to suckling age. No other data are provided in the lists. For the complete set of data see Table 1. The tablet contains an obvious scribal error (*) in year 46, where the amount of cheese is specified as 4 3/4 ban₂, but the total amount of cheese mentioned on the reverse implies 5 1/4 ban₂.

The interpretation of the tablet has been a matter of debate. Gelb (1967) assumed that it records the evolution of an actual cow herd and its production of butter oil and cheese. Vaiman (1971) convincingly showed that the data were computed⁵. The same conclusion was drawn, seemingly independently, by Nissen, Damerow and Englund (1993)⁶. Clear indications for the theoretical nature of the data are the absence of mortality in the herd and that each cow produces the same constant amount of butter oil and cheese irrespective of age. Another indication is the schematic nature of the herd’s annual growth.

In other words, AO 5499 records the outcome of a simulation. Note that since the data are accompanied by historical year names, the simulation was

⁵In the words of Vaiman (1971: 53): “The text TCL, II, 5499 is the only Sumerian document in which the dynamics of herd growth is the subject of computation”.

⁶In the words of Nissen, Damerow and Englund (1993: 99–100), “it seems quite clear that, for reasons unknown to us, the text represents a trial or model calculation concerning hypothetical herd growth”. See also Englund (1995: 389–392), who qualified the text as “entirely theoretical”. In a similar vein Robson (2008: 74) concluded that “because simple arithmetical rules govern the model of growth, and because the herd is not assigned to a shepherd or otherwise located in the real world, it is probably not a straightforward record of actuality”.

performed after Šulgi year 48. How was the model system updated from year to year, and what was the initial state? As argued by Vaiman (1971: 49), and Nissen, Damerow and Englund (1993: 97-100) the updating was achieved with highly schematic rules concerning the birth rate of calves, their gender, and the amounts of butter oil and cheese produced by each cow. Cows from age 4 are counted as mature, but, as pointed out by Vaiman (1971: 49–51), the data indicate that they only produce calves, butter oil and cheese from age 5⁷. This can be seen by dividing up the mature cows into 4-year-old cows and older cows (Table 2), assuming that in year 39 all cows have reached age 5, and comparing the number of cows older than 4 years with the number of calves and the amounts of butter oil and cheese produced in each year.

year	39	40	41	42	43	44	45	46	47	48
4-year-old cows	0	0	0	0	1	1	1	1	1	1
cows >4 years	4	4	4	4	4	5	6	7	8	9

Table 2: Number of 4-year-old cows and cows older than 4 years.

After these preparations, the following updating rules can be inferred from the data on the tablet:

- 1) add 1 year to the age of each animal;
- 2) from age 5 each cow produces 5 sila₃ (= 1/2 ban₂) of butter oil and 7 1/2 sila₃ (= 3/4 ban₂) of cheese per year;
- 3) from age 5 each cow gives birth to 1 calf every second year;
- 4) each new calf in the herd is alternatingly male and female.

Rule 3 is slightly different from the corresponding rules as reconstructed by Vaiman (1971: 49, rule 2) and Nissen, Damerow and Englund (1993: 100). In both studies it was assumed that the number of calves was computed as half the number of cows and that any half integer outcome was rounded to an integer. In the present reconstruction no rounding or truncation is necessary. The precise manner in which rule 4 was implemented is open to debate. In the present reconstruction a strict alternation of male and female

⁷According to Nissen, Damerow and Englund (1993: 97–100), and Englund (1995: 389), calves are produced from age 4 and the number of calves is half the number of mature cows truncated to a whole number. Butter oil and cheese are also assumed to be produced from age 4, but the amounts produced in a given year are assigned to the next year (see Nissen, Damerow and Englund 1993, 101: Fig. 78). No plausible justification is given for this delay.

year	total						year	total										
39	bull calves	1				1	44	bull calves	1		1		2					
	cows >4 yr	a	b	c	d	4		cows >4 yr	a	b	c	d	e	5				
	heifer calves	1				1		heifer calves	1				1					
40	bull calves	1				1	45	bull calves	1				1					
	cows >4 yr	a	b	c	d	4		cows >4 yr	a	b	c	d	e	f	6			
	heifer calves	1				1		heifer calves	1	1				2				
41	bull calves	1				1	46	bull calves	1		1		2					
	cows >4 yr	a	b	c	d	4		cows >4 yr	a	b	c	d	e	f	g	7		
	heifer calves	1				1		heifer calves	1				1	2				
42	bull calves	1				1	47	bull calves	1	1				2				
	cows >4 yr	a	b	c	d	4		cows >4 yr	a	b	c	d	e	f	g	h	8	
	heifer calves	1				1		heifer calves	1	1				2				
43	bull calves	1				1	48	bull calves	1		1		1	3				
	cows >4 yr	a	b	c	d	4		cows >4 yr	a	b	c	d	e	f	g	h	i	9
	heifer calves	1				1		heifer calves	1				1	2				

Table 3: Visualization of rules 1, 3–4 for each year of the simulation with the expected numbers of bull calves and heifer calves. The encircled numbers in year 46 and 48 deviate from the tablet (see main text).

calves is maintained within each year and from one year to the next year. What was the initial state of the system? Since the tablet is damaged near the top left edge almost no data are preserved for year 39. The amounts of butter oil and cheese which are legible in obv. i 5–6 imply that there were 4 mature cows of age 5 or more in that year. For the remaining data of year 39 we can compute backwards from year 40. The 1-year-old calves in that year were suckling calves in year 39. The production of butter oil and cheese is counted from year 39 onward and in principle the simulation could have been initialized in that year, but going back one more year yields 4 cows and 0 calves in year 38, which might be viewed as the underlying initial state for the cows⁸.

The simulation can now be reconstructed as follows. 1) The system is initialized in year 39 with 4 cows of age 5 years or higher. 2) The gender of all calves is determined (rule 4) by defining the first calf in year 39 to be male. 3) The system is updated ten times with rules 1–4. The resulting development of the herd is shown in Table 3. Until year 45 the data on the tablet (Table 1) are reproduced, but in year 46 the reconstruction yields 2 heifer calves + 2 bull calves instead of 1 heifer calf + 2 bull calves, as pointed out by Vaiman 1971 and Nissen, Damerow and Englund (1993)⁹. However,

⁸See also Vaiman (1971: 50).

⁹See also Vaiman (1971: 51), and Englund (1995: 390, footnote 29).

if we continue the simulation in year 46 with the anomalous 1 heifer calf + 2 bull calves by omitting the heifer calf produced by cow g in Table 3 then the data for years 47–48 are reproduced. In other words, the deviation in year 48 of the reconstruction (Table 3) can be interpreted as a consequence of the deviation in year 46. Also note that rule 2 is satisfied without exception if the amount of cheese in year 46 is corrected to $5 \frac{1}{4}$ ban₂, as explained above. The close agreement between the reconstructed simulation and the data on the tablet leaves no doubt that they were updated with rules 1–4 or very similar rules. The text ends with an account of the total number of cows and bulls in the final year and the total amounts of butter oil and cheese produced over the entire interval covered by the simulation. The amounts of butter oil and cheese are also converted to silver using the rate $10 \text{ sila}_3 \text{ butter oil} = 150 \text{ sila}_3 \text{ cheese} = 1 \text{ shekel of silver}$.

The total amounts reported at the end of the tablet presumably define the ultimate purpose of the simulation. An interesting aspect is that even though the updating rules are simple, they generate a rather complex sequence of states. Certainly no alternative, non-iterative method was available to the Mesopotamian scribe for computing these total amounts. The only available method was to carry out the complete simulation.

What do we gain by interpreting AO 5499 as a simulation? In the simulation-based view one expects the time development of a model to be merely sufficiently similar to that of the corresponding real system. What counts is that the simulation succeeds in answering the question that was posed by the scribe. In this case the purpose was probably to compute the total number of calves and production of butter oil and cheese, and not the individual components of the cow herd and its annual production as accurately as possible. Indeed, the simulation clearly amounts to an approximative and highly idealized model system. Empirical knowledge about the evolution of cow herds and their production of butter oil and cheese was transformed into highly idealized updating rules and annual production rates. In particular, there is no mortality in the herd and the birthrate of the calves is only half as large as expected¹⁰ – deviations from empirical reality which the scribe was obviously aware of. The simulation-based approach suggests that these features can be interpreted in terms of a “balance of approximations”. That is, one process – mortality – is ignored and the resulting deviations from empirical reality are counterbalanced by modifying another model parameter, in this case the birth rate. The underlying

¹⁰Vaiman (1971: 51); Englund (1995: 394, footnote 37).

assumption was, probably, that the combined effect of these manipulations cancels out with respect to the total production of butter oil and cheese. What interested the scribe was not how many cows died or how many calves were born, but how much butter oil and cheese would be produced after a given number of years. But the simulation-based view also leaves room for other interpretations, such as the one offered by Vaiman (1971: 51–52). He proposes that the tablet reflects an agreement between an owner of four cows and a shepherd to whom he has entrusted the cows in year 38 for a period of ten years. According to Vaiman the computation only concerns that part of the herd and its dairy production which the owner expects to receive from the shepherd in years 39–48, while any surplus becomes property of the shepherd. In this interpretation the anomalously low birth rate could reflect a balance of approximations involving two causes of depletion to the herd, namely mortality plus whatever the shepherd is allowed to keep for himself in return for his work.

3 Conclusions

The purpose of this contribution was to explore the simulation-based approach as a tool for interpreting Mesopotamian iterative computations. It was inspired by recent investigations by Francesca Rochberg in which she argues for a model-based approach to Mesopotamian astral science (Rochberg 2016; 2018) and by recent developments in the philosophy of simulation. The aim of the exploration is not to project modern conceptions on ancient practices or to localize the “origins of simulation”, but to show that certain Mesopotamian computational practices can be better understood in this manner. Indeed, the Ur III tablet about herd growth that was presented as a case study exhibits features that are not at all unexpected in the simulation-based view. For instance, important components of the simulation model, such as the mortality and birth rate of cows, deviate strongly from their actual values, which the Mesopotamian scribe was obviously aware of. Other Mesopotamian sources that could be fruitfully approached in a simulation-based framework are various groups of Babylonian tablets with astronomical predictions. In particular the tables with planetary, lunar and solar data computed with mathematical astronomy (Neugebauer 1955), the corresponding procedure texts (Ossendrijver 2012), and the predictive Goal Year Texts (Hunger 2006) and Almanacs (Hunger 2014) may be mentioned. By directing our attention

to iterative numerical modeling as a means to make sense of the world and predict its phenomena, the simulation-based view may also help to counteract outdated, Eurocentric historiographies of science that continue to view axiomatic-deductive systems as a privileged form of knowledge. As mentioned, the simulation-based approach asserts that the dynamical systems which are modeled by ancient scholars and modern scientists only correspond to real systems to a certain degree, depending on the purpose of the simulation. As shown by philosophers of science, this is actually how modern scientists view their computer simulations (Winsberg 2009: 836). We can therefore conclude that it would be inappropriate to expect anything different from an ancient scholar.

Acknowledgements

This article was written in the context of the project ZODIAC – Ancient Astral Science in Transformation financed by the European Research Council (ERC Advanced Grant) under the Horizon 2020 framework (Grant Agreement No. 885478).

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