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Abstract Diagrams make wonderful templates for technical action. It follows that for scholars of science and technology they are both an object and a tool of study. The author explores this relationship in the first part of the article, focusing on one particularly effective format for communicating or retrieving complicated technological sequences: the *chaîne opératoire*, or procedural sequence. Today we usually think of a diagram as a graphic, but diagrammatic thinking is also frequently expressed in other forms, including text or hybrids of graphics and text. To illustrate this, the author compares the formulation and use of chaînes opératoires in two canonical Chinese agricultural treatises. The *Qimin yaoshu* (*Essential Techniques for the Common People*) by Jia Sixie, completed ca. 540 CE, was composed before printing was available and makes no use of graphics. The *Nongshu* (*Agricultural Treatise*) of 1313, authored by Wang Zhen, was published using woodblock print, a medium that facilitated Wang's copious use of graphics. The comparison between these classic treatises invites reflection on how the material techniques of inscription available to an author might influence their diagrammatic thinking. But the chaîne opératoire is good to think with at a more general level too. For historians, the matches or discrepancies between the chaîne opératoire they might draw up to map a technical operation, and the versions that they find in historical sources, suggest ways to think both about technology as a total social fact, and about differences between cultures of communication.

Keywords chaîne opératoire · procedural sequence · diagram · history of technology · agriculture · China · nongshu

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Diagrams make wonderful templates for technical action, material or mental (Bray 2007a). This method of simplifying messy material reality, the equivalent of translating a living landscape into a plan, offers a highly effective way to inscribe or transmit the complexities of material techniques in terms that are easy to understand, and good to think with. It follows that for scholars of science and technology, diagrams are both an object and a tool of study. It is this relationship I explore in the first section of this article, focusing on one form of diagram that is especially frequent in our sources, and especially apt for inscribing and transmitting technical information: the *chaîne opératoire*, or procedural sequence.

Today we usually think of a diagram as a graphic, but diagrammatic thinking is also frequently expressed in other forms, including text, or hybrids of graphics and text. To illustrate, I compare the formulation and use of chaînes opératoires in two canonical Chinese agricultural treatises. The *Qimin yaoshu* (*Essential Techniques for the Common People*) by Jia Sixie, completed ca. 540 CE, was composed before printing was available and makes no use of graphics. The *Nongshu* (*Agricultural Treatise*) of 1313, authored by Wang Zhen, was published using woodblock print, a medium that facilitated Wang's copious use of graphics. The comparison between the Chinese works invites reflection on how the material techniques of inscription available to an author might influence their diagrammatic thinking. But the chaîne opératoire is good to think with at a more general level too. For historians, the matches or discrepancies between the chaîne opératoire they might draw up to map a technical operation (as discussed in the first section of this article), and the versions that they find in historical sources (as described in the second), suggest ways to think both about technology as a total social fact, and about differences between cultures of communication.

As STS scholars or historians, we often sketch diagrams as a way to map and assess the assemblages, interchanges, flows, and procedures that we study (Box 1). We are particularly grateful when our sources contain recognizable diagrams of their own to help us along the way. When historians of technology try to make sense of ancient techniques or modes of operation, they pray that their sources will contain reasonably complete chaînes opératoires outlining as fully as possible each stage of the technical process, along with the variants that determine technical choices along the way. Not surprisingly, very few sources are so obliging. If the information is there, it will likely be scattered, incomplete, and presented in unfamiliar formats. Even in a document in which how-to instructions are laid out as successions of skilled material interventions, in what historians of premodern science and craft commonly refer to as a "recipe" and I have just termed a chaîne opératoire, the instructions may cover only some stages and not others, or essential knowledge may be deliberately omitted because it is sacred, or to keep the secret of the art from noninitiates. Since artisans in any society were seldom literate, this means that many early crafts and skills that historians of technology would like to reconstitute and understand are available to us at best through artifacts and contextual sources, but not through direct textual descriptions or graphic depictions.

In that respect, the case with which I have chosen to illustrate the utility of the chaîne opératoire as a tool of analysis, namely agriculture in imperial China, was an exceptional case: it was a legitimate field of knowledge and practice for the ruling elite, a continual preoccupation of emperors and their ministers and of the landed gentry, and copiously documented in a range of administrative and technical documents. These included numerous agronomic treatises (*nongshu*) that provided "how-to" instructions

Box 1.   Historians' diagrams: mapping the production of tea in British India.

In a recent project on the circulation of technical knowledge and technological artifacts (Bray 2019), I set out to trace whether and how the various elements brought from China to India in the 1830s shaped the distinctively Indian tea industry that took shape over the next decades. I made extensive use of the chaîne opératoire to organize the information in my copious but very heterogeneous sources into a reasonably complete account of the technological basics of Indian tea production and their variants; why they took the form they did; how and why they changed over time and as the industry expanded into new territory; and how the dynamics, general characteristics, and basic techniques of the Indian industry differed from those of its Chinese progenitor and competitor.

The following diagrams, which break down the chaîne opératoire of tea production at different levels, illustrate the flexibility of this diagramming method. Focus, scale, and scope can all be adjusted depending on the information the figure is intended to highlight.

Figure 1a. is a basic working diagram I constructed for heuristic and organizational purposes. It shows a sequence of nine phases in tea production, traced forward from the acquisition of suitable land to the brewing of a pot of tea. This diagram was devised on the basis of "practical reason ontology" (Dobres, cited in Kuijpers 2012: 139): all nine phases are materially necessary, in that order, to the eventual brewing of a pot of tea. Some of my sources—Chinese, British and Indian—divided tea production into more or less identical phases to mine, but none covered all nine. Tea retailers, historians of consumption or labor historians, shareholders and planters, legislators and botanists were all concerned with different ranges.

Figure 1b. is an exploratory exercise in mapping how institutional, social, environmental, and cultural factors affected both individual phases and the general contours and scale of tea production in British India. The pertinent factors ranged from British imperial legislation on land purchase to rampaging elephants; divisions of technical skills and labor by race, class, and caste; and shifts in consumer taste, nudged by tea companies away from light Chinese-style teas that were difficult and expensive to produce in India toward a preference for the strong, dark teas that Indian estates could produce cheaply and in abundance. Drawing several versions of this rough sketch, focusing on different actors or procedures, was very helpful as I sought to understand linkages between biological and social factors, technological choices on the tea estates or company headquarters, and the dynamics of the industry.

Figure 1c. is a flow chart illustrating the technical sequences that process fresh tea leaves into different types or grades of tea. Versions of this flow chart can be found in tea-industry or agronomic publications as well as connoisseur consumer or retail websites. This diagram (a break-down of phase 6 in Fig. 1) was particularly useful to me as I organized my source materials to trace the complex evolution of tea-making skills and techniques in India as they evolved from Chinese-style teas to the new Indian-style teas (Wikimedia Commons 2008).
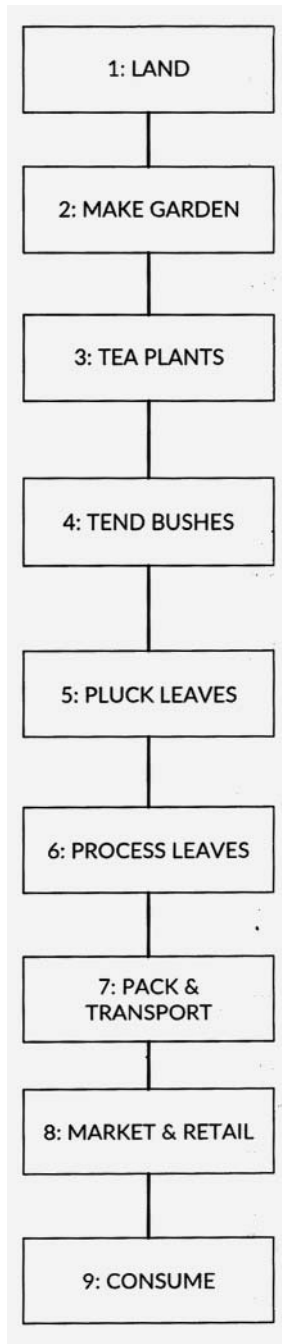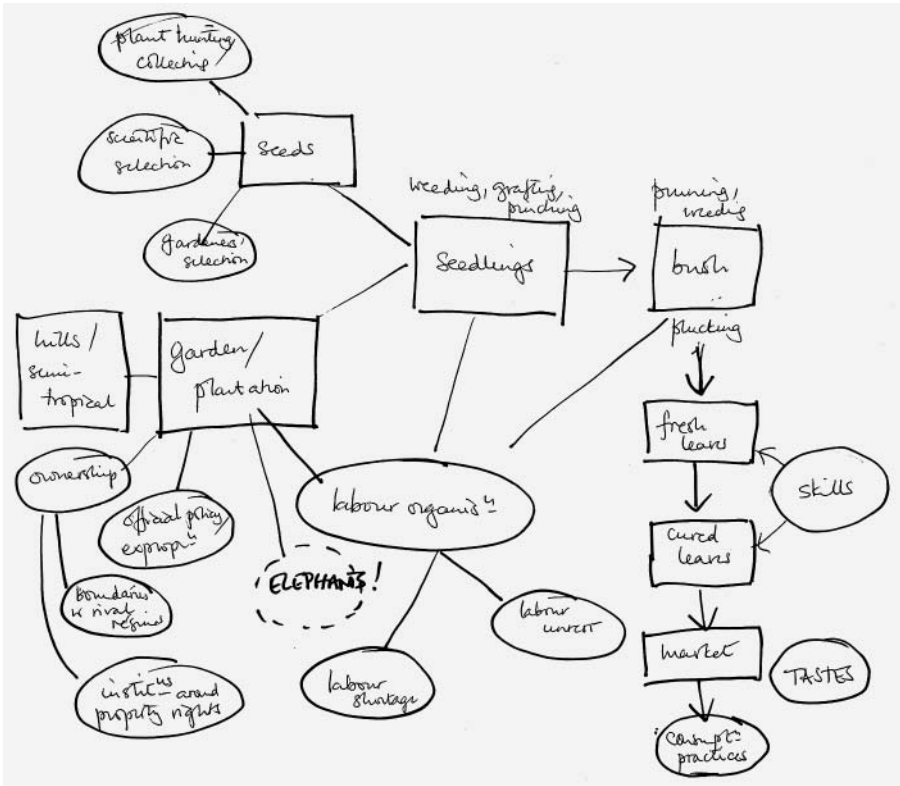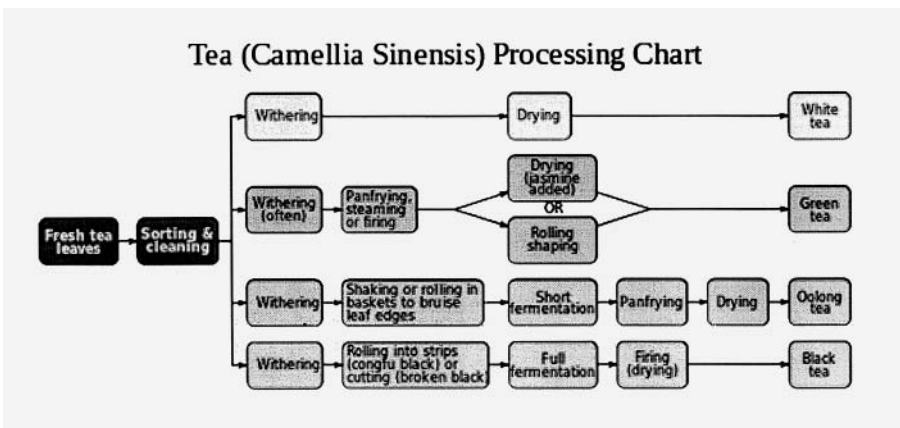
Figure 1a

Figure 1b

Figure 1c

written either by officials for other officials working with local farmers, or by literate farmers whose intended audience was basically other literate farmers (Bray 2008). Documentation and discussion of the technical details of farming continued through the two millennia of imperial rule. The conventions of technical writing used in

Chinese agronomy merit attention not only in their own right but also because they provide an unusually richly illustrated example of a mode of technical writing whose stylistic conventions and pedagogical devices were shared across technical or intellectual fields, including architecture (Steinhardt 2019), forensics (Will 2019) and mathematics (Chemla, this issue).

Before proceeding to analyze how information is organized in my Chinese agronomic sources, however, I want to discuss how we as historians or social scientists use diagrammatic representations of knowledge both to organize our research investigations and to demonstrate our findings.

1 Thinking (and Writing) with Diagrams: The Case of the Chaîne Opératoire

One well-developed type of graphic representation of technical procedures and technological cultures that French anthropologists, historians, archaeologists, and social scientists associated with the journal *Techniques et culture* have worked with for some time is the *chaîne opératoire*, or procedural sequence. This concept has also been taken up by many archaeologists in and beyond France (e.g., Schlanger 1994; Dobres 2010; Kuijpers 2012).

The fundamental concept of the chaîne opératoire is Durkheimian-Maussian. This approach to interdisciplinary technography (Jansen and Vellema 2011) was first developed by two students of Mauss: the anthropologist, archaeologist, and linguist André Leroi-Gourhan (1943–45, 1964–65) and the anthropologist, linguist, ethno-botanist, and ethno-zoologist André-Georges Haudricourt (1988). It was subsequently elaborated for specific application to complex technological processes in the journal *Techniques et culture*, by an interdisciplinary group which has included, on and off, most of the leading figures in actor-network theory (ANT) and related approaches to technology, including the anthropologist and theorist of technology Pierre Lemonnier (see, esp., Lemonnier 1992, 1993) as well as Tim Ingold (2007, 2011).

From the Maussian perspective, a technological artifact or practice brings together the material, physiological, and conceptual-linguistic skills of craft, social relationships, and symbolic codes of value, including the ritual, the cosmological, and the aesthetic. The processes of the chaîne opératoire could thus be studied either with the wide-angle analytical lens as a total social fact (an activity with symbolic, political, and relational as well as material dimensions), or in close-up as a mode of material making or social negotiation (Coupaye 2009). As a mapping technique, however, the chaîne opératoire can be adapted perfectly well to other political-theoretical perspectives, for example a Marxist enquiry into technological discipline, reification, deskilling, or the making of subjectivities.[1]

A researcher may be content with a chaîne opératoire that focuses only on the sequences and conjunctions of material inputs and techniques that go into producing an artifact (Fig. 1a). But because the concept intentionally offers scope to incorporate all the actions and procedures, social and symbolic as well as material, that go into

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[1] On the genealogies of the Maussian-Durkheimian tradition of cultural technology and its relation to Marxism, see Naji and Douny 2009; Warnier 2009.

producing a human artifact (Fig. 1b), we can include in our chaîne opératoire the ritual offerings and the sociable sharing of betel nut that are an integral part of producing a barnful of ripe yams (Coupaye 2009), or the encounters between cosmologies and work disciplines that went into "taming" a French-designed gasogene so that it would work more or less reliably in the backwoods of Costa Rica (Akrich 1993).

Actor-network theory, as developed by Madeleine Akrich, Michel Callon, and Bruno Latour, was part and parcel of the interdisciplinary project of French anthropologists and sociologists to push forward more effective ways to study technology (e.g., Akrich 1992). While some were more interested in the dynamics of reproduction of technological systems, the ANT specialists wanted to chart transformation and innovation, seeking ways to capture the continuously changing networks of association that bring about new objects and new worlds. Latour (famous as a producer of provocative graphics of all kinds) has organized whole books, including *Aramis; or, The Love of Technology* (1996), as complex, interwoven narrative-graphic chaîne opératoire accounts of the creation (or failure) of new technologies. Latour's graphic rendering of "the story of the Aramis switch," for example, itself switches between textually rendered snippets of conversation and sketches of circuit connections to show successive stages in the design of the switch at two levels: the verbal exchanges between engineers and workers that led to changes, and the new structure of the switch that resulted from these expert discussions (Latour 1996: 244).

There is no standard symbolic code or set of conventions for drawing a chaîne opératoire, whether in textual or graphic form, or a combination of both. Indeed to provide an adequate account of a technology in context, it may be necessary to map various elements separately, and in different formats. At its simplest level, the chaîne opératoire is conceptually and analytically similar in many respects to the kinds of process portrayed in flow charts or organizational charts (Fig. 1c).

Even when broken down into elements, however, the chaîne opératoire is caught in an essential tension, between the simplification inherent in the flow chart's categorizations and codifications of inputs, outputs, and relationships, on the one hand, and, on the other, the need to render complexity, the categoric and qualitative specificities of real-life material cultures, and the ambiguities of an entity that might at once be an asset or a liability, a subject or an object. Is it possible somehow to capture both these levels in a textual structure or visual code, or at the very least to devise a system for moving back and forth between different levels of complexity or specificity, and different registers of action and experience? For a historian of technology, this applies both to our sources (which necessarily address this tension), and to our reconstitutions of historical technical processes. The issue has attracted a lot of debate, particularly among archaeologists (e.g., Knappett 2011; Kuijpers 2012).

So what does a good account of a technological procedure, past or present, look like? In *Reassembling the Social: An Introduction to Actor-Network Theory*, Latour (2005) turns his critical attention back to the term *network*, which he wishes to restore to the powerful analytic it once was, before the internet (and social science models) debased the term into a descriptor for any association of two or more elements. Curiously, here Latour uses no graphics at all, apart from a few photographs. Instead he focuses on "narrative" and "text," and the telling of the pared-down, essential elements of a story:

What is a good text? . . . I would define a good account as one that traces a network.

I mean by this word a string of actions where each participant is treated as a full-blown mediator. To put it very simply: A good ANT account is a narrative or a description or a proposition where all the actors do something and don't just sit there. Instead of simply transporting effects without transforming them, each of the points in the text may become a bifurcation, an event, or the origin of a new translation. As soon as actors are treated not as intermediaries but as mediators, they render the movement of the social visible to the reader. . . . A text, in our definition of social science, is thus a test of how many actors the writer is able to treat as mediators and how far he or she is able to achieve the social. . . . .

So how can we define by contrast a bad textual account? In a bad text only a handful of actors will be designated as the causes of all the others, which will have no other function than to serve as a backdrop or relay for the flows of causal efficacy. They may go through the gestures to keep busy as characters, but they will be without a part in the plot, meaning they will not act. . . . Remember that if an actor makes no difference, it's not an actor. (2005: 129–30)

This principle of exclusion would reduce a Dickens novel to a slim volume, and eliminate all the red herrings from detective stories. But, as Latour says, a social scientist is not dealing in literature. As historians, though, we might see this ruthless scientific focus as a denial of the importance of context. Certainly there has been a tendency to reconstruct the chaînes opératoires of long-lost technologies within this "practical reason ontology" (Dobres, cited Kuijpers 2012: 139; Fig. 1a), reaching back from the material characteristics of a surviving artifact through a strictly materialist style of reverse-engineering: "The process [of prehistorical metal working] is clearly perceived as purpose oriented, meaning that every step in the technological *chaîne opératoire* needs to have purpose, which is the creation of the actual artefact. It is furthermore taken for granted that these purposes are rational and efficient in terms of modern epistemologies and ontologies" (Kuijpers 2012: 139).

But the chaîne opératoire does not necessarily apply only to networks in the strong Latourian sense; it can also be used to chart systems more comprehensively, to include elements that may initially seem nonfunctional or inert, like junk DNA (Fig. 1b). Thus if a background element proves later to be a functional factor, there is room for it in the diagram. One beauty of the chaîne opératoire for the researcher is its supreme flexibility, including its breadth of compass and register. Although it can be ruthlessly pared down to essentials, the same chain can be expanded to accommodate, if need be, context, nuance, or atmosphere. It can be adapted to incorporate what Dobres calls the "cultural reason approach" (Dobres, cited in Kuijpers 2012), the fingertips reasoning of craft decisions, the nuance of bitterness that the professional tea taster requires of a good-quality blend of Ceylon tea, or the vision of misty southern peaks and cliffs evoked by the perfume of a Song Dynasty tribute tea (Bray 2019; Hinsch 2015). Rituals are an essential component of many technical activities, but might be dismissed by agnostic observers as superstition that is nonfunctional. In the Chinese agronomic texts I work with, quotations from poetry or history, anecdotes, and personal recollections are often not directly functional, yet they enrich the scope of technical information or serve to anchor it in the mind.

Mapping the same chaîne opératoire at different scales and locations, from different angles and at different levels of focus and detail, permits us to move into close focus to peer at an Indian High Range tea picker's fingers as they rejected damaged leaves to pluck only the finest tips, or to draw back to consider the financial institutions or even the racial science that underwrote the plantation economy of British India (Bray 2019). Indeed, in a recent essay included in Ingold's (2011) *Redrawing Anthropology*, the classical historian and archaeologist Carl Knappett argues precisely for developing the chaîne opératoire for this purpose (Knappet 2011: 51). In an influential recent move in the anthropology of material culture, Ingold has proposed a distinction between two distinctive "topologies describing material distributions through time and space"; the *network* ("a series of identifiable nodes with connections between them"), populated by *objects* (clearly bounded and defined); and the *meshwork* ("a maze of overlapping and intersecting lines"), populated by *things*. A thing may be the self-same artifact as an object, but viewed from its perspective as enmeshed: a hammer in use (an integral element in a skilled manual action) as opposed to a hammer lying next to a wrench in a tool-box. Knappett argues that we need a means to look at how these contrasting ontologies and topologies are articulated.

Ingold's prevailing concern, in *Redrawing Anthropology* and previous works, criticizing what he views as the static and reductionist tendencies of the diagram, is how to address creativity, improvisation, and invention, how to treat them as at once out there in our environment and in ourselves bodily and mentally as part of the environment. Ingold's concern is to treat the material world not as a surface to be surveyed (one of his bugbears) but as flows, eddies, and confluences. For Ingold, drawing a line or a diagram, like walking or making a net, training a reindeer or felling a tree, is a way to use our own bodies to "follow the material" (Ingold 2011: 4) and thus to understand better the dynamics of material culture and its role in our daily lives.

But how, concretely, are we as researchers to "follow the material," to bind together networks and meshworks, asks Knappett?

> I have not seen different kinds of meshworks documented and compared. So . . . I want . . . to *develop a methodology*. Why the reluctance, if that is what it is, to develop or promote a methodology for following materials? *A perfectly good methodology—the chaîne opératoire——is already available* for doing just this, which makes its non-adoption in the context of "following the materials" all the more puzzling. Or is it? In some guises the *chaîne opératoire* has looked very *prescriptive* rather than *descriptive*: a means to reconstruct mental templates underlying technological action. This points us towards the approach of "looking at and surveying artefacts" rather than that of "following materials." It separates mind and matter, locking creativity into the interior world of the mental template. This can be seen in some of the very formal flow diagrams, which appear to dictate where materials *should* go, rather than following where they actually go.

> Another potential of the *chaîne opératoire*, though not always exploited, is *its capacity to allow for zooming in and zooming out*. . . . It could provide us with the *bridge* we need between the meshwork and the network, between the object and the thing. (2011: 51; emphases added)

Knappett argues that Ingold has gone too far in his abhorrence of routine and repetition in cultural expression: they are necessary elements of material and technical action, even where it involves improvisation. "But is it only the analyst who, in some circumstances, sees a technological sequence in simplified, typological terms? Might there not also be *an emic dimension to this—a kind of routinisation or formalisation, whereby techniques can be reduced to their main components for the sake of sharing and transmission*?" (Knappett 2011: 52; emphasis added).

We need to include the possibility of standardization and abstraction, argues Knappett, not just for our own exterior understanding of other people's material culture or technical activities, but also to allow for the *emic* understandings through which technical activities are reproduced by an individual or group, transmitted within a culture, or passed on to later generations or other societies.

So far I have focused on the chaîne opératoire primarily as an etic tool for the historian, anthropologist or STS scholar seeking to retrieve and organize information about other people's technical procedures. Now I turn to emic chaînes opératoires as objects of study, devices frequently used in the technical texts that we study as historians of technology, which invite closer analysis. I examine two agronomic treatises produced in imperial China, to explore where and how the authors packaged information in diagrammatic form, how this information was structured and layered, and which diagrammatic formats, textual or graphic, they considered effective.

2 Thinking with Chaînes Opératoires in Chinese Sources

Here I discuss the use of chaîne opératoire–type diagrams, graphic and/or textual, to render technical knowledge in one of the most voluminous genres in Chinese writing, namely, agronomic treatises, or *nongshu*. China has a particularly rich and continuous tradition of agricultural writing. The earliest texts date back to at least the fourth century BCE, and the flow of agricultural writing continued unabated into modern times (Wang 1979; Bray 1984). The principal goal of these texts was to transmit practical knowledge, to describe agricultural techniques and practices in such a way that the essential features could be understood and materially reproduced. They are technological texts, designed "to transmit technological information to someone who [can] use it in a technological way" (Long 2007: 6). They unfold sequences of operations, adjusted according to resources and prevailing conditions; when an author argues with the earlier authorities he is quoting, it is typically on the grounds that what the earlier text advocated does not work in his region, that a new technology or method has superseded the earlier practice, or (sometimes) that the author cited was plain ignorant and was doing things wrong (Bray 2008). This may seem unsurprising viewed from today's perspective, but in the context of Chinese writing the agricultural literature is unusual for its plain material focus and its plain technical language, with learned perorations on philological interpretation, cosmology, or the art of rule typically confined to the preface and concluding pages.

At the core of these Chinese agronomic treatises are chaînes opératoires, how-to instructions (*prescriptive*, in Knappett's terms) laid out as successions of skilled material interventions. In classical Chinese in general, and in these treatises, such

procedural sequences are typically referred to as a *method* (*fa* 法).[2] Now, these *fa*, or procedural sequences, are not diagrams in the strict modern sense, for they are expressed in text, or in a pairing of text and image. However they are formatted to give the reader a sense of relationships, an ordering of events in time and space, a sequence of steps or set of algorithms with ordered options for variation. They are, in other words, chaînes opératoires.

3 Diagrammatic Organization of Information in the *Qimin Yaoshu*

To illustrate some Chinese approaches to diagrammatic thinking, I first present some key features of the chaînes opératoires for farming operations found in the sixth-century agricultural treatise *Qimin yaoshu* 齊民要術 (*Essential Techniques for the Common People*).[3]

Almost everything we know about the practicalities of agriculture in early China comes from this one landmark work, completed sometime between 533 and 544. The *Qimin yaoshu* was immensely influential, setting the pattern for almost all later agricultural treatises. After discussing the diagrammatic elements in the *Qimin yaoshu*, I briefly mention how its style of purely textual technical diagram or chart was elaborated as new media for textual production became available.

The author of *Qimin yaoshu*, Jia Sixie 賈思勰, was an estate owner and practicing farmer who had served the Northern Wei government as a mid-level official. Half of the content of this ten-volume treatise consists of Jia's original text, the other half of quotations drawn from around 160 works that span the seven centuries preceding the *Qimin yaoshu*'s composition. Jia's nongshu covers the production of field crops, fruits, vegetables, and timber as well as animal husbandry, the raising of silkworms, and various forms of food processing. The scale of Jia's calculations suggests that his treatise was intended for owners of large estates combining subsistence production with commerce.

It may seem exaggerated to claim that an agricultural treatise should be classed among the written masterpieces of the Six Dynasties (220–589), a period renowned for some of the most beautiful and ornate literature ever written in China. The author of the *Qimin yaoshu* does not dazzle his readers with poetic ingenuity, nor does he expound subtle aesthetic or philosophical theories, or offer esoteric instruction in the arts of transcendence. Instead, in clear, terse, and sober language, and in an elegantly logical construction, Jia offers his readers comprehensive technical instructions for an utterly mundane but morally sacred activity: farming.[4]

It is no simple matter to develop effective conventions for communicating technical information, as the savants of the European Enlightenment discovered (Popplow 2010). In China, a plain, precise technical language for writing about farming, apparently rooted in the vernacular, developed very early. This is the language Jia uses in *Qimin yaoshu* for his technical instructions, and it is presented in his text in large

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[2] As opposed to a *fang* 方, recipe or prescription in medicine and related arts; the modern Chinese for *method* combines both terms, *fangfa* 方法.

[3] See Bray 2016, which also provides a bibliography of Chinese and Japanese editions of and scholarship on *Qimin yaoshu*.

[4] On the moral significance of farming as material, social, and political activity, see Bray 2007b.

Table 1 *Qimin yaoshu* table of contents

Juan	Chapter	
		Xu 序 preface
		Za shuo 雜說 miscellaneous remarks
I	1	*Geng tian* 耕田 clearing and tilling land
	2	*Shou zhong* 收種 collection and treatment of seed grain
	3	*Zhong gu* 種穀 cultivation of setaria millet
II	4–16	Cultivation of field crops (cereals, beans, etc.)
III	17–29	Cultivation of vegetables
	30	*Za shuo* 雜說 miscellaneous remarks (including *yueling* 月令 monthly calendar)
IV	31	*Yuan li* 園籬 planting hedges
	32	*Zai shu* 栽樹 transplanting trees (general rules)
	33–44	Fruit trees and Chinese pepper
V	45	*Zhong sang zhe* 種桑柘 mulberry trees (*yang can fu* 養蠶附 appendix on sericulture)
	46–51	Timber trees and bamboo
	52–54	Dye plants
	55	*Fa mu* 伐木 cutting timber
VI	56–61	Animal husbandry (including poultry and fish)
VII	62	*Huozhi* 貨殖 the profits of trade
	63–67	Brewing
VIII	68–79	Culinary preparations (soya sauces, vinegars, preserved meats, etc.)
IX	80–89	Culinary preparations (meats, cereal dishes, candies, etc.)
	90–91	Glue making, preparation of ink, brushes, etc.
X	92	Grains, fruits and vegetables not indigenous to North China

characters. Jia's philological discussions of terminology, his quotations and anecdotes, are presented in small characters (a double column of text in small characters inserted into the single column of main text in large characters is the classic mode in Chinese texts for differentiating commentary from the main text). Jia's explanations or elaborations of the instructions in the main text are also given in small characters.

It is not easy to tell just how innovative Jia's work and its organization were, given that so little of the earlier agronomic literature has come down to us in its original form. However, in his preface Jia makes a big point of explaining how he has structured the work to make it user-friendly: he tells us how he has organized the work into ninety-two *pian* 篇, or chapters, divided into ten *juan* 券, or volumes, with a table of contents (*mulu* 目録) at the beginning of each book (see table 1). Jia's insistence on this point strongly suggests that the structure of the *Qimin yaoshu* and its user guide, the nested table of contents, were an innovation at least within the agronomic tradition.

A *mulu* 目録 is literally a record for the eye, or a list of headings, laid out so the reader can grasp the work's contents and their ordering at a glance. In other words, it is a diagrammatic representation, but not a chaîne opératoire. The organizing principle of the individual chapters, however, is the chaîne opératoire. Each chapter begins with a discussion of the varieties of the crop, their uses, where they are found, and the literary works that refer to them. After these preliminaries (which give scholarly authority to the work as a whole) Jia provides a chaîne opératoire for cultivation: treating the crop systematically from seed preparation, ploughing, sowing, and hoeing through to harvesting and storage, a basic procedural sequence of the type shown in figure 1a. The

overall sequence is broken up into subsequences for each operation (a structure similar to figure 1c), and those subsequences in turn are elaborated to allow adaptation to circumstances. Soil type, weather (especially rainfall or frost), phases of the moon, auspicious or inauspicious days, and market demand are woven into this much more complex overall chaîne opératoire, encompassing a pattern of factors, suggestive of figure 1b, that helps us as historians to reconstruct Jia's farming techniques and the social world in which they were embedded, to view a crop and its cultivation as a total social fact.

Abstracting, for the moment, to the basic material-technical operations, here is Jia's system in action. For each farming operation he describes, Jia offers general principles followed by specific advice matched to variations in climate, soil type or weather. Procedures are outlined step by step, and Jia's commentary (shown here in round brackets) provides explanations of how they work or under which conditions they are necessary. This format for instructions on crop cultivation became the model for almost all later agricultural treatises (including Wang Zhen's *Nongshu* of 1313, discussed below). Here is a typical passage, giving instructions for cultivating setaria millet, *gu* 穀, the main staple crop of northern China (Miao and Miao 1982: 43):[5]

> Spring sowing should always be deep, so draw a *ta* 撻 [a bush weighted down with stones] over the seed. Summer sowing should be shallow, so just sow the seed directly and leave it to sprout on its own. (In spring the soil is cold and germination slow. If you do not use the *ta* the roots will spread into empty cracks [in the soil] and even though the plant germinates it will soon die. In summer the air is hot and germination rapid. If you use the *ta* and then it rains the soil will become compacted.)[6]

Here Jia gives instructions for the variant procedures for sowing either in spring or in summer, explaining why they need to be different. This is typical. Jia also routinely offers variant techniques, organized in triads, for drier, medium, or wetter soils; for fertile, medium or poor land; for early, medium, or late sowing or planting: for each crop we are presented with an adaptable chaîne opératoire that could usefully serve in almost any arable region in northern China (see table 2).

Rainfall was generally scarce in this climatic zone, and manures or fertilizers were, as in almost any premodern farming system, always in short supply. Jia shows us a technical system that countered these disadvantages. A range of methods helped maximize the moisture retention of the soil. They included turning in green or animal manure; careful and repeated harrowing and hoeing to produce a soil mulch and keep down weeds; and planting crops with a seed drill, spaced and in rows, to give each plant maximum access to moisture and fertilizer. Furthermore, the *Qimin yaoshu* integrated sophisticated crop rotations as standard practice into its instructions. The rotations alternated greedy crops like millet with crops like beans, known to restore soil fertility and improve its texture. Again we proceed in triads to provide flexibility: the best sequence might not fit current market demands or the domestic needs and resources of the farm estate (see table 3).

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[5] In the translated passages, I use round parentheses to show Jia's comments on his main text, or to insert a Chinese term used by Jia; I use square brackets to indicate where I myself have added explanations for clarity.
[6] See Bray 1984: 272–73 for an explanation and illustration of the *ta*.

Table 2 *Qimin yaoshu* planting calendar

Crop	Best sowing period	Medium period	Last possible	Sowing rates
Foxtail millet	1st *xun* 旬 [10-day period] of 2nd month (hemp flowers and willows come out)	1st xun of 3rd month (peach starts to bloom)	1st xun of 4th month (mulberry starts to bloom)	5 sheng 升/mu 畝 on good soil, 3 on poor (1 sheng or pint/mu is roughly equivalent to 1 litre/600 square meters.)
Broomcorn millet	1st xun of 3rd month	1st xun of 4th month	1st xun of 5th month	4 pts/mu
Soy beans	2nd xun of 2nd month	1st xun of 3rd month	1st xun of 4th month	8 pts/mu for best period, 10 for medium, 12 for last
Adzuki beans	10 days after summer solstice	Just before dog-days	Just after dog-days	8 pts/mu for best period, 10 for medium, 12 for last
Hemp for fiber	10 days before summer solstice	Summer solstice	10 days after summer solstice	2 pts/mu
Hemp for oil seed	3rd month	4th month	5th month	3 pts/mu
Wheat	Early in 8th month	Middle of 8th month	End of 8th month	1.5 pts/mu for best period, 2 for medium, 2.5 for last
Barley	Middle of 8th month	Late 8th month	End of 8th/early 9th month	1.5 pts/mu for best period, 2 for medium, 2.5 for last
Rice	3rd month	1st xun of 4th month	2nd xun of 4th month	3 pts/mu of pregerminated seed
Sesame	2nd, 3rd months	1st xun of 4th month	1st xun of 5th month	3 pts/mu

Jia's structuring and substructuring of the *Qimin yaoshu* is such that it is extremely easy to follow the chaîne opératoire for any individual crop from seed selection and soil preparation through to harvesting and storage (often with additional notes on processing or even recipes using the crop as an ingredient). We might say that in diagrammatic terms Jia presents us with a set of parallel, longitudinal, crop-centered chaînes opératoires. But no farmer grew just one crop. It is not as easy to extract from the *Qimin yaoshu* a timeline for farm management: here we are in April, with the plum trees coming into bloom, so what should we be doing around the farm?

Jia would have expected his readers to read his treatise with reference to a complementary, alternative format for agricultural instructions, the *yueling* 月令 (monthly ordinances, or farming calendar). Here all the farm and household activities typical of a particular month, from ploughing cereal fields to mending ropes, along with the sacrifices and rituals that fell in that month, and advice on which crops to buy and which to sell, would be grouped in a single chapter. The yueling format—facilitating the organization of time and labor and connecting the timing of operations to such phenological signs as catkins blooming or the first frosts, along with calendrical-astrological information about auspicious and inauspicious dates and hours for

Table 3 *Qimin yaoshu* crop rotations

Crop to be sown	Recommended preceding crop di 底 (in order of excellence)
Foxtail millet	Green gram
	Adzuki bean
	Cucurbits
	Hemp
	Broomcorn millet
	Sesame
	Rape turnip
	Soybean
Broomcorn millet	Soybean
	Foxtail millet
	Newly opened land
Adzuki beans	Wheat or barley
	Foxtail millet
Hemp	Adzuki beans
Cucurbits	Adzuki beans
	Late foxtail millet
	Broomcorn millet
Wheat or barley [winter crop]	Broomcorn millet
Rape turnip	Wheat or barley
Coriander	Wheat or barley
Lithospermum officinale (*zi cao* 紫草) [dye plant]	Wheat or barley
	Non-glutinous broomcorn millet
	Newly opened land

different activities—has a venerable history dating back to pre-imperial times (Dong 1981). Jia includes a section of yueling instructions in the chapter titled "Miscellanous Advice" ("Za shuo" 雜說, chap. 30), where he proffers quotations from a medley of works within the yueling genre. And within his longitudinal chaînes opératoires Jia systematically quotes from works like the *Simin yueling* 四民月令 (*Monthly Ordinances for the Four Classes of People*), written ca. CE 160 by Cui Shi 崔寔. Throughout imperial times the yueling format continued to prosper in parallel, and in complement, to the nongshu format (Dong 1981).

4 New Media, New Messages? The Impact of Printing

The *Qimin yaoshu* was one of China's best-known and most influential farming treatises. It circulated widely in official and private circles before the printing era began in the tenth century. Very soon printed editions were issued by the state for distribution to local magistrates; commercial publishing houses also found a ready market for the work. The *Qimin yaoshu* set the pattern for the sections on crop plants in later agronomic treatises, but the new medium of woodblock print allowed for an elaboration of some domains of technical communication. As was typical of works written before printing, the *Qimin yaoshu* contained no graphics beyond the table of contents,
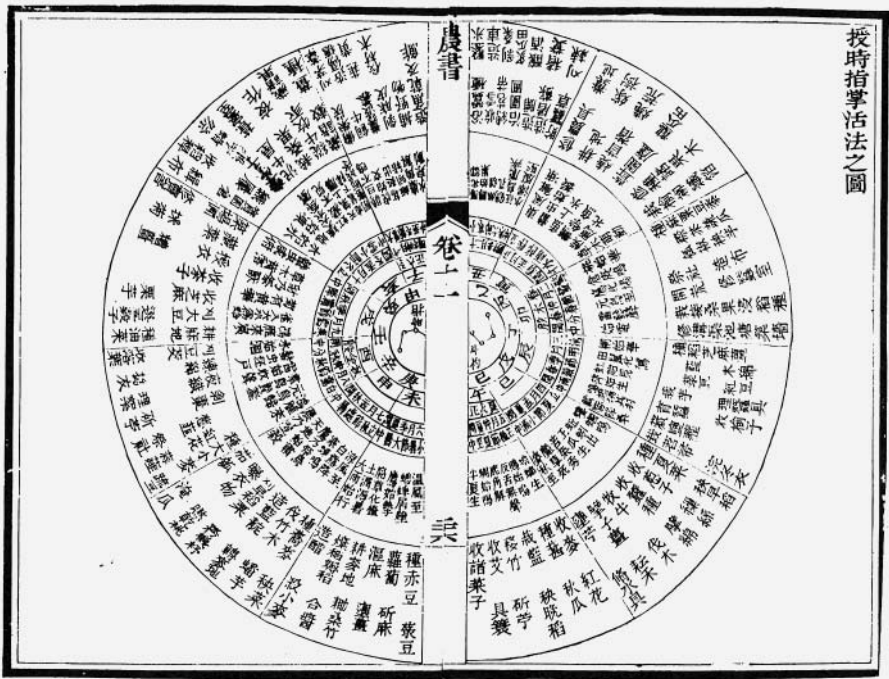
Figure 2 Wang Zhen's universal calendar (as reproduced in Wang 1981: 195). This calendrical diagram, titled *Shoushi zhizhang huofa zhi tu* 授時指掌活法之圖 (*Simple Diagram for [Calculating] Variations in the Seasons Granted by Heaven*), combines in concentric rings the astrological, lunar, and solar calendars; the changing configurations of the constellations; and the annual sequence of agricultural tasks and the phenological signs that herald them: "all the essential points of a traditional Chinese farming almanac united in a single small circle" (Bray 1984: 53–55).

whereas print-era treatises like Wang Zhen's 王楨 *Nongshu* 農書 (*Agricultural Treatise*) of 1313 were able to complement written explanations with wood-block illustrations (Bray 2007a, 2007b), devising new formats of chaînes opératoires.

Wang's *Nongshu* offered a comprehensive treatment of agriculture throughout the Chinese empire of the time. It treats both northern and southern farming systems, and it goes beyond *Qimin yaoshu* in scope, since it is organized around the pairing of men's and women's labor and social contributions, including both crop cultivation (men's work) and textile production (women's work) (Bray 2013: 57–89). Like the *Qimin yaoshu*, Wang's *Nongshu* circulated widely and was highly influential, finding favor both with officials, who commissioned numerous editions over the centuries, and with commercial publishing houses catering to an apparently insatiable market for handbooks on technical subjects ranging from agriculture and medicine to ritual, letter-writing, and law (Chia 2003; Chia and De Weerdt 2011).

Wang's *Nongshu* was the first illustrated agricultural treatise.[7] Wang mobilized the graphic possibilities of printing both to improve existing formats for communicating the operational sequences of farming and to devise new formats.

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[7] Elsewhere I compare the pedagogical strategies and aesthetic choices of Wang Zhen's treatise to a slightly earlier and very famous depiction of the successive phases of rice farming and silk production, the *Gengzhi tu*

With the advent of woodblock printing, many cosmological, astrological, and astronomical charts were translated into print format, circulating widely. The yueling or monthly calendar had figured in textual form in the *Qimin yaoshu* as the cross-cutting cyclical temporality within which the linear temporalities of crop cultivation were embedded. Wang's *Nongshu* includes a graphic yueling. This calendar incorporates all the astronomical, astrological, phenological, and other information into a single circle of concentric rings, similar to the geomantic compass (Skinner 2008). Wang joyfully claimed to have devised a universal calendar that could be adapted according to simple principles to work in any climatic zone. His graphic yueling took what is to us today the recognizable form of a diagram (Fig. 2).

Wang's yueling diagram constituted an improvement that presented existing chaînes opératoires more effectively. It was a visual aid intended to help a farmer find his way easily through the complex maze of calendrical prescriptions. The term *zhizhang tu* 指掌圖 (simple guide, lit. "finger and palm diagram") referred to the mnemonic system of hand diagrams popular in medicine and divination. Hand diagrams located key technical information at specific locations on the hand, allowing the practitioner to see at a glance how different elements in a calculation connected (Hanson 2008; Homola 2015).

But Wang did not confine his graphic ambitions to improving existing formats for communicating agronomic information. He also innovated. A major section of Wang's treatise, a total of twenty out of thirty-six *juan*, pairs illustrations and text to describe varieties of field types, farming implements and equipment, ranging in complexity from watermills to sandals, from harrows to spinning-wheels. The *Nongqi tupu* 農器圖譜 (*Illustrated Register of Agricultural Implements*) is a superb account of the tools and machines that fed and clothed China. It contains altogether 261 entries, each of which pairs a line drawing of agricultural or textile equipment with text detailing the parts of the tool or machine and their dimensions, how they fit together, the purposes for which the tool was used and its advantages or disadvantages in different contexts (Bray 2007b).

The *tupu* 圖譜, or illustrated register, was a new genre of communicating technical information that had emerged during the Song Dynasty, soon after the routinization of printing. It paired an illustration, *tu* 圖, with a corresponding text, *wen* 文. The epistemological or cognitive case for this pairing was spelled out by the Song scholar Zheng Qiao 鄭樵 (1104–62). Zheng insisted that *tu* played as essential a part as written words in the techniques or arts of learning, *xueshu* 學術. The best way to convey specialist information was to lay it out in an illustrated register, *tupu* 圖譜, a sequence of rubrics where for each item a graphic illustration was paired with an explanatory text.

> The images (*tu* 圖) are the warp threads and the written words (*shu* 書) are the weft. As warp and weft alternate to form the pattern of a fabric (*wen* 文) [so images and written words alternate to form the meaning of a text (*wen* 文)]. . . .

耕織圖 (*Pictures of Ploughing and Sericulture*). This was an album painted by a local magistrate, Lou Shu 樓璹, and presented to the emperor in about 1140 (Bray 2007b; Hammers 2011). In a nutshell, I argue that, despite the technical detail of its images, the *Gengzhi tu* was intended as much for moral as for technological instruction. It did, however, provide a detailed technical chaîne opératoire both for rice farming and sericulture, and as such has been an invaluable resource for historians of technology.

To see the writing without the image is like hearing a voice without seeing the form; to see the image without the writing is like seeing a person but not hearing his words.[8]

During the Song Dynasty *tupu* were devised for a wide range of technical fields, among them building, mathematics, military science, cosmology and astronomy, linguistics, administration, and the study of ritual—but curiously, not for agriculture.[9]

Why, then, did Wang choose to apply this new approach to the transmission of farming knowledge? The chaînes opératoires of the *Qimin yaoshu*, often quoted verbatim but with additional observations and comments, form the bulk of Wang's chapters on the dry-land crops of northern China, and provide the model for his treatment of wet rice and other new crops not included in the *Qimin yaoshu*.[10] The *Qimin yaoshu* specifies which implement to use for which operation, but provides no information about the construction of farm tools or machinery. Wang, however, saw this information as a valuable, even essential, addition to his treatise.

Wang's *Nongshu* was a response to crisis. Wang was a native of Shandong province, in the north, and had spent many years as an official in Anhui and Jiangxi, in the south. Most farming regions in China were still suffering badly from the aftermath of decades of warfare between the Southern Song and Yuan states. Wang urged magistrates to acquire a thorough practical understanding of the best agricultural methods currently available, to instruct the peasants under their jurisdiction. He considered that his treatise provided informed and accurate documentation of effective tools and methods from around China; he was especially interested in technology transfer between north and south. His basic method was to document existing high-quality practices to facilitate their dissemination.

Wang's hope was that officials would make use of his work to introduce more-advanced technology to backward regions, and to disseminate various items of labor-saving or helpful equipment to areas where they were unknown. This motif occurs again and again in the opening sections of the *Nongshu*, for instance in the chapter on harrowing (*balao* 耙勞), which includes the many different types of harrow that existed for stirring the mud in rice paddies, smoothing seed into dry-land furrows, creating a soil mulch, and so on. "I am including all of them here," says Wang, "so that northern and southern knowledge can be exchanged, and people can use whatever is most suitable" (Wang 1981: 27).

So Wang's purpose in composing the *Illustrated Register* was not simply to provide an inventory of the most common farm implements and machines. His pairing of text and graphics was intended to provide the right information, in the right format, to allow his readers to reconstruct the equipment. To effect this technology transfer, they needed instructions for building the devices (Bray 2007b: 538).

Take the square harrow, *ba* (方耙) as an example (Fig. 3). The text next to the image reads, "The length of the cross-bars should be five feet, the width four inches; the two beams should be five inches or more apart. Each is pierced with square holes in which

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[8] Zheng Qiao, *Tupu lüe* 圖譜略 (*Brief Account of Tupu*), quoted Bray 2007a: 1.

[9] Unless we count the *Gengzhi tu*, which was conceived not as a treatise but as an album of paintings.

[10] See Bray 2008 on how instructions for cotton cultivation developed as it became a familiar crop on Chinese farms.
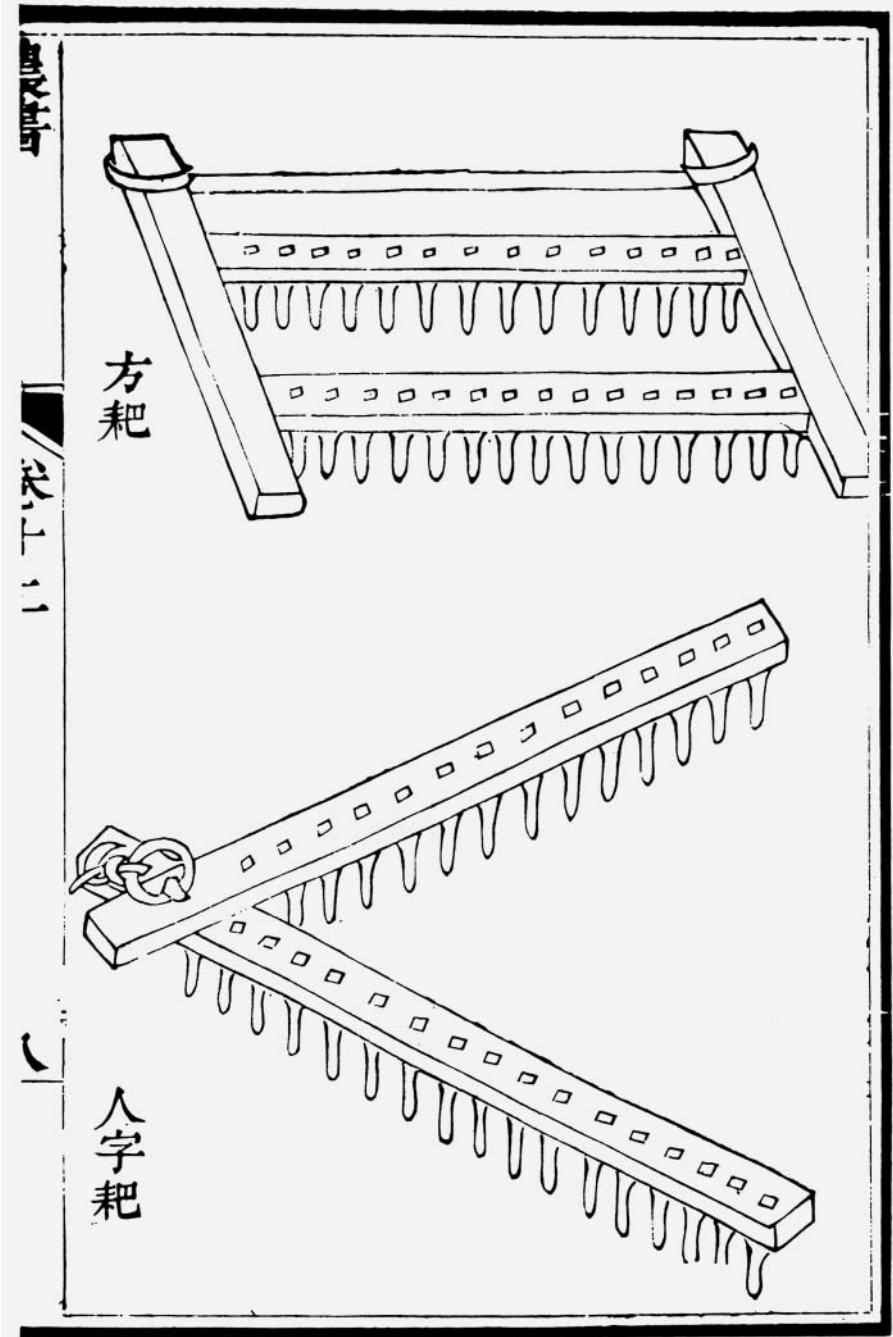
Figure 3 Entry for toothed harrows in Wang Zhen's *Illustrated Register* (as reproduced in Wang 1981: 205). The square harrow (*fang ba* 方耙) is shown above, the V-shaped harrow (*renzi ba* 人子耙) below.

are set wooden teeth six inches or more long. At each end of the cross-bar is a wooden beam about three feet long, curved slightly upwards at the front end and pierced by a wooden peg to which the ox's traces are attached" (Wang 1981: 205).

There is no doubt that Wang composed this *tupu* entry as a practical guide to constructing a square harrow. This we know not only from his stated hopes that the treatise would facilitate technology transfer but also from an account of how he produced the *tupu* images and text. According to Wang's friend and fellow prefect Dai Biaoyuan 戴表元, as well as observing and interviewing the local farmers about their methods Wang "also made drawings (*tuhua* 圖畫) of all the varieties of hoes, drills, harrows, and other miscellaneous implements, and had the common people make them (*shi min wei zhi* 使民為之)," a method that initially caused merriment among his colleagues and bewilderment among the farmers, but which according to Dai showed its value in disseminating best practices in just a few years.[11] In other words, Wang was at pains to record the construction of farm implements in detail, based on the sequence of operations that he observed workmen following in "making them."

Yet, as a chaîne opératoire these *tupu* entries are, to our modern eyes, glaringly incomplete. We see a huge hole in the information Wang provides how to fit the pieces together. But consider the context in which the chaîne opératoire was conceived. The magistrates or other readers of Wang's treatise were educated men with no craft skills. Their relationship to the desired product was in several key respects comparable to that of today's Ikea customer, who likewise lacks (or is presumed by Ikea to lack) any relevant technical skills. Wang's readers, like Ikea customers, were given a picture of what the assembled piece of equipment should look like, and a list of components. But unlike the Ikea customer, they were not given the set of ordered operations (graphic or textual) that provided the procedural sequence for assembling the parts, nor did they have the magic square key to bolt the bits together. And while Ikea furniture packs contain assembly-ready parts, Wang simply listed the necessary components without providing any instructions for making them even though he specified their shape, dimensions, and material.

Why did Wang not feel compelled to include instructions for making and assembling the parts? What to us is a blank, for Wang was a clear, time-honored step in a partnership of skills. Wang assumed that the officials or landowners who were his readers didn't need to be told how to assemble a harrow (it's unlikely, despite Wang's own empirical observations, that he could have done it himself), because he knew they would delegate this part of the decoding of his instructions to a carpenter (*mujiang* 木匠). Carpenters were the universal workmen and repair men of imperial China, the mechanics of the time. They built everything from houses to temples and public granaries, furniture and farm equipment, draw-looms and chain pumps for irrigation (Ruitenbeek 1993). A man of letters like Wang could count on hiring a carpenter to fill in the technical blanks. As Wang says further on in the *Nongqi tupu*, in his account of the rotating mechanism of the chain pump, "its assembly involves many complicated joints: you will need to use a carpenter, who will build it easily" (Wang 1981: 326). The carpenter provided the *working knowledge* (Harper 1987), the unwritten experience, material skills, and holistic apprehension of a technical operation, which

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[11] See Dai's preface to the *Nongshu*, Wang 1981: 445.

allowed the completion of Wang's partial prescription, and the transformation from a blueprint on paper into the construction of a hitherto unfamiliar piece of equipment.

We have no way of knowing the extent to which the *Nongshu* fulfilled its author's ambition to transfer useful technical devices from their regions of origin around China. As the writer of the preface to his friend's treatise, Dai Biaoyuan naturally claimed that the *tupu* method was a resounding success. But carpenters working freelance, farmer-to-farmer exchanges, or introductions by merchants—all areas of activity that are almost entirely undocumented in the imperial record—were equally likely agents of change. That said, throughout the late imperial period many local officials enthusiastically pursued the introduction of new tools, crops, and methods, and consulting works, including the *Nongshu* and others similarly organized to transmit technical knowledge, for prototypes (Bray 2008).

And what of the carpenter's ability to fill in the gap in the chaîne opératoire, thus translating Wang's *tupu* text-image pairing into a concrete artifact? In building, this partnership of *tupu* and working knowledge was well established. Well-known works included the *Yingzao fashi* 營造法式 (*Treatise on Architectural Methods*) and the *Ziren yizhi* (*Traditions of the Joiner's Craft*).

The *Yingzao fashi*, completed in 1103, was compiled on imperial orders by Li Jie 李誡, a highly experienced architect and supervisor of public building works, an employee in the Department of Construction who rose to the position of director. Widely used on public projects, the work has survived in its entirety. The *Yingzao fashi* contains numerous *tupu* of different types of building and their components, providing not absolute but scalar measurements so the model could be adapted to different sizes. The technical drawings of joinery, notably the complicated beams and trusses characteristic of formal architecture, are of impressive quality. In addition to his own experience designing buildings and managing their construction, Li was said to have "questioned craftsmen who explained everything" (Ruitenbeek 1993: 27).

The *Ziren yizhi* 梓人遺制 by Xue Jingshi 辥景石 was completed in 1264. Xue seems to have been a member of the local gentry in a small northern city, an experienced woodworker and enthusiastic collector of wooden objects and apparatuses. "He made drawings of each of them, listed their measurements, and described their manufacture. In all, 110 items were treated in his book. *He then showed it to other woodworkers, and they could understand ninety percent of it*" (Ruitenbeek 1993: 31–32; emphasis added). Xue's entries began with one or more drawings, followed by "a list of parts and measurements (*yong cai* 用材, "materials needed"), and a list of the number of labor units (*gong* 功) needed to finish the various parts of the item" (32). Although the *Ziren yizhi* has since been lost, 9 out of the original 110 entries (for different types of loom, yarn-reeling devices, doors, and a carriage) were included in the imperial encyclopedia *Yongle dadian* 永樂大典 (completed 1408), suggesting that the work was well-known in Wang's time.

The practice of officials or private clients sharing *tupu* with carpenters continued, as we can see from the *Lu ban jing* 魯班經 (*Carpenters' Canon*). This compilation, still cherished as the sacred text of their craft by the few surviving traditional carpenters, may first have been compiled in the early 1400s, around the same time as the imperial encyclopedia. The instructions for constructing houses and other buildings, items of furniture and everyday equipment, follow the *tupu* format. Unlike Wang's *tupu*, which contain only material instructions, the *Lu ban jing* entries incorporate social factors,

ritual, astrological calculations, and magical spells, all definitely part of the chaîne opératoire as far as carpenters and their clients were concerned, but not admissible in a work by a rational official like Wang. Some items (water pumps and looms, for example) overlap with Wang's repertory, but the texts and drawings are different.

To summarize, the medium of woodblock printing allowed Wang to adapt to agriculture new diagrammatic formats for communicating technological procedures that were complementary to those devised by earlier authors, notably Jia Sixie, working in the preprint era. The textual diagrammatic formulae that Jia used in the *Qimin yaoshu* to provide complex, multilayered procedural sequences for growing specific crops in a diverse range of conditions produced information in a form that proved sufficiently effective or persuasive to be reproduced extensively. Instructions from the *Qimin yaoshu* were incorporated into agricultural treatises of the print era without later authors, including Wang, feeling any need to modify the format or to devise graphic illustrations to supplement the type of information they provided. Instead, the innovative contribution of Wang was to use the new medium of woodblock print to fill a gap in the technical information contained in the *Qimin yaoshu* and other earlier agronomic works, namely, farm toolkits and the methods for making them. Wang adapted the new, print-based format, the *tupu*, or illustrated register, for agricultural purposes. The individual entries in Wang's *Nongqi tupu* (*Illustrated Register of Agricultural Implements*) paired image and text to offer a chaîne opératoire for constructing the device in question. As a register or repertory, Wang's *tupu* served as the equivalent of a catalogue from which he expected serving officials to select suitable new or improved items to add to the local toolkit. The corresponding image-text pair was to be shared between officials and carpenters, with the carpenters supplying "working knowledge" of what to the historian's eye looks like a conspicuous gap in the full procedural sequence of construction, namely, how to fit the components together.

5 Concluding Remarks

This essay has proposed a particular format of diagrammatic formulation of technological knowledge, the chaîne opératoire, as a helpful device for building constructive dialogue between the historian of technology and her sources. I began by pointing to the uses of the chaîne opératoire as both a heuristic and an organizing device for historians and other scholars researching technological practices. Using arguments and examples from technology studies and from my own research on the history of tea, I suggested that the chaîne opératoire provides the historian or social scientist with a flexible template for mapping and retrieving the sequences, locations, and associations of material operations, while accommodating the social and symbolic elements that make technological action a form of cultural production, a total social fact.

Not all of our sources on technology contain information organized by our historical actors (or live interlocutors) as chaînes opératoires. This is typically the case in archaeology, for example, where the chaîne opératoire proves its value as a heuristic and analytical tool not only for tracing the material operations that make up a technological practice but also for suggesting what their meanings and impact might have been at the time.

But many of the technical texts with which historians of technology work do contain chaînes opératoires, complete or partial, single- or multistranded, composed of text, graphics, or a play between the two. In the second section of this essay, I explored the differently formulated chaînes opératoires used by two imperial Chinese authors of highly successful and influential agronomic treatises, one writing in the preprint era, the other in the print era. I suggested that close scrutiny of these formulations is valuable not only because of what it tells us about past technological practices but also because of what it tells us about our historical actors' models for pedagogical communication. My examples suggested that an author's choice of format depended partly on the very specific characteristics of the knowledge field involved (here, agriculture), partly on the available media for transmitting information (the advent of printing opened new possibilities for technical communication in China as elsewhere), and partly on the broader culture of knowledge production, its devices, resources, and fashions.

The various types and combinations of chaîne opératoire devised by ancient Chinese agronomists offer an unusual degree of congruence between the goals of the authors and the expectations or hopes of a historian of technology: they spell out procedures in order, offer variants depending on circumstance, give information for constructing the tools of the trade, and suggest how to nest the linear temporalities of a crop season within the cyclical temporalities of the calendar or a crop rotation cycle. But expectations met are only part of the reward of matching the "practical reason ontology," the sequential steps of the chaîne opératoire that the historian might initially draw up to map the technical activity, to the instructions in the ancient agricultural treatise. It is where the match fails, when we as historians identify apparent gaps, and unexpected components or linkages, that diagrams past and diagrams present become really good to think with.

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