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This is the synthetic biology that is[☆]

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Synthetic: How Life Got Made, Sophia Roosth. University of Chicago Press, Chicago, USA (2017). pp. 256, Price $105.00 cloth, ISBN: 978-0-226-44032-3

Synthetic Biology: A Sociology of Changing Practices, Andrew S. Balmer, Katie Bulpin, Susan Molyneux-Hodgson. Palgrave Macmillan, Basingstoke, UK (2016). pp. 207, Price $100 hardcover, ISBN: 978-1-137-49541-9

From its origins in the early-2000s, synthetic biology was characterized by the drive to create and design life, a rhetoric of bringing engineering into biology, communities organized around a handful of colorful personalities, and breathless *Wired* magazine coverage. Strip away these veneers and what emerges is a loosely organized attempt to turn microbes into the material substrate for engineering projects. What separates synthetic biology from beer brewing or industrial fermentation is its ambition to edit or rewrite whole microbial genomes. Synthetic biologists have been working to create the biological equivalent of machine tools and interchangeable parts standards to accomplish just that. Now in its adolescence, it cannot be said that synthetic biology has matured into a discipline, a set of technologies, or even a cluster of core concepts. Rather, it has taken shape as a far vaguer set of ideals and attitudes, which run alongside prevailing regulatory, economic, and technological conditions. The cultural sensibilities of synthetic biology are fairly specific as well, and what we have today is the result of a collision between academic microbiology and the Silicon Valley-MIT-venture capital nexus and its derivatives: more Uber, Theranos, or DARPA than Cambridge's Medical Research Council or the IEEE.

The two new books under review here are part of a wave of scholarly and journalistic books examining this emerging field.[1] Science studies scholars have been in close contact or otherwise engaged with synthetic biology since its origins (e.g., Calvert, 2008; Campos, 2009, p. 8n; Keller 2009; Morange, 2009; Rabinow & Bennett, 2009; 2012), drawn to its endeavors to create and redesign life itself. But this creation-evangelism has obscured what synthetic biologists are actually busy doing. Both *Synthetic: How Life got Made* and *Synthetic Biology: A Sociology of Changing Practices* suggest that we should be paying closer attention to synthetic biology's other founding mythology: the promise to simplify genetic engineering, making it cheap and easy enough for anyone to do. And, by implication, they suggest that we have only begun to understand the people who do synthetic biology: where they come from, and exactly what kind of engineering ideals they possess.

Synthetic biology's most recognizable elements carry over from the middle years of the George W. Bush presidency: a rhetoric around building or synthesizing organisms as "devices" for particular ends; a commitment to standardizing DNA "parts" in order to simplify microbial engineering; and the continued emphasis on the analogy between genes/organisms as computer software/hardware. Two of synthetic biology's core institutions are still hosted at MIT, as they have been since 2004: the Registry of Standardized Biological Parts remains the epicenter for the BioBrick™ standard for genetic parts, while the annual iGEM (International Genetically Engineered Machine) competition, where teams of undergraduates create novel synthetic organisms using BioBricks, remains synthetic biology's marquee event.[2] Amyris, one of the most visible synthetic biology biotech companies today, was founded by UC Berkeley chemical engineer Jay Keasling in 2003; the Emeryville, California company's now-legendary breakthrough came in 2006, when Keasling's team successfully engineered the metabolic pathway of *Saccharomyces cerevisiae* to produce the antimalarial drug artemisinin (Roosth pp. 61–64; Grushkin, 2012, pp. 110–21). And it is still worthwhile to follow Bernadette Bensaude-Vincent's lead (2013a) and look back to a pair of oft-cited papers from 2005, one by Drew Endy, the other by the chemists Steven Benner and A. Michael Sismour. All three scientists had emphasized employing an engineering ethos to create interchangeable biological parts, but from there they diverged. Endy's vision centered on standardizing genetic parts and simplifying biology through decoupling, abstraction, and design, whereas Benner and Sismour's more ambitious future envisioned chemically

[☆] With apologies to Luis Campos (2009).

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[1] Among many others: Church and Regis (2014); Ginsberg et al. (2014); Porcar and Peretó (2014); Wohlsen (2011).

[2] The 2016 iGEM contest drew 5600 participants from 42 different countries, likely making iGEM the largest synthetic-biological activity by participation. iGEM is supposed to inculcate synthetic biology in young students, as well demonstrating more globally that synthetic biology makes biological engineering easy enough for young people to do in just a few months.

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synthesizing an alternative and simplified genetic code, and creating standardized genetic and enzymatic parts *de novo*. Thus, Benner and Sismour sought to understand life by creating it anew, while Endy sought the democratization of understanding life by making genetic engineering faster and easier.

Andrew S. Balmer, Katie Bulpin, and Susan Molyneux-Hodgson's *Synthetic Biology: A Sociology of Changing Practices* is an ethnographic study of a synthetic biology project that began in 2009 at the University of Sheffield that brought interdisciplinary academic expertise in bioengineering into the UK water and sewage industry.[3] This adventurous, government-funded project was intellectually and geographically far from MIT, and this distance is the basis for the book's most immediately useful insight: that synthetic biology has both a core and a periphery. The "core" consists of aforementioned and oft-studied actors, institutions, geographical locations, and even rhetorical tics such as standardization and BioBricks. The "periphery" is any local context in which the core is enacted in various ways as a distant goal, a model to be emulated, or a set of institutional inequalities or challenges (pp. 19–21): Sheffield and the UK water and sewage industry are as peripheral as it gets.

One quickly realizes that the "changing practices" in this highly reflexive book refer to sociologists' practices, rather than those of the biologists, and in *A Sociology of Changing Practices*, the ethnography is merely a proving ground for the latest theories and interests in STS. Chief among these practices is the "post-ELSI" intervention that anthropologist Paul Rabinow and religious studies scholar Gaymon Bennett (2009, 2012) pioneered while embedded within UC Berkeley's synthetic biology initiative.[4] Rather than being detached observers who theorize about future consequences of scientific research, this post-ELSI approach has sociologists directly intervening and collaborating in the scientific project as it develops. Early on, Balmer, Bulpin, and Molyneux-Hodgson ran into resistance and skepticism over these post-ELSI methods: some of the scientists were confused by the active presence of sociologists in their spaces, and the scientists did not see the sociologists as collaborators working on equal terms. The scientists thought the sociologists ought to act either as being "representative of the public" at large, as the scientists' communicators to the public, or as mediators within a complicated interdisciplinary and industry-academia project (pp. 72–79).

Balmer, Bulpin, and Molyneux-Hodgson are part of a larger cohort of British sociologists who are pursuing post-ELSI analyses of synthetic biology (see Marris et al., 2015; Balmer et al., 2016). The water and sewage project *A Sociology of Changing Practices* is based on ended in 2012 with mixed results, however, and the authors admit they never quite achieved their goal of being active co-producers of knowledge within synthetic biology (p. 72). Meanwhile, their role as advisors to Sheffield's struggling iGEM team in 2010 had some unexpected consequences: "If we were not responsible for puncturing [the students'] initial enthusiasm we were at least culpable in cultivating a more cynical attitude amongst the team … promoting the notion that there was no possibility for change or agency in their work" (p. 150). Arguably Balmer, Bulpin, and Molyneux-Hodgson are most successful highlighting imagined and imperceptible barriers to collaboration within the project, the subject of the book's second and most effective chapter. Not only were there the usual cultural and disciplinary barriers that the project's academic engineers, molecular biologists, industry R&D managers, and sociologists had to cross. The project was also hemmed in by regulations in law and in grant proposals, perceptions of government regulation, and the specter of public misunderstanding of science. One of the authors' most surprising conclusions is that industry actors ought to try harder to understand—or at least be sympathetic to—academic researchers' incentives and work habits as the latter try to solve the problems of the former. It's a nice inversion of the stereotype of narrow-minded academic researchers butting heads with innovation-hungry industry, a trope that pervades many technology transfer initiatives.

The rest of *A Sociology of Changing Practices* pursues two other recent STS trends: ontological enactments, and the affective or embodied dimensions of scientific research. As for the former, this "ontological turn" in STS is a radicalization of actor-network theory and has been promoted by Annmarie Mol (2002, 2013), Steve Woolgar and Javier Lezaun (2013, 2015), and John Law and Marianne Elisabeth Lien (2013), among others; there have been vigorous critiques and protests of this trend in STS as well (Lynch, 2013; Sismondo, 2015; Aspers, 2015; see also Schaffer, 1991). *A Sociology of Changing Practices* tries its hand at this ontological turn in STS by demonstrating how bacteria are "bio-objectified" through "*bio*graphical enactments," concluding that "ontological shifts in bacteria occurred through bio-objectification processes that were entangled with changes in disciplinary identity and the construction of a new sociotechnical field," i.e. synthetic biology (p. 96). By way of example the authors recount how one of the chemical engineers and one of the water engineers on the project were reminded that bacteria are living organisms rather than particles in a physical suspension, and they were happy to learn some microbiology during the course of the project. But it is not clear if "bacteria" in this sense is the analyst's or the actor's category: it applies to two of the engineers, though I suspect that molecular biologists and microbiologists might think that "bacteria" is too high of a taxonomic level to be useful, and that they would prefer to work on more specific species like *E. coli*, *B. fragilis*, or *Saccharomyces cerevisiae* (a yeast, not a bacterium, though there is no chapter on "yeast" or "fungi") or specific strains thereof.

As the authors pursue the non-human actor "bacteria," the ethnographic focus unfortunately slips away from the already complicated synthetic biology and water industry project. An eyebrow-raising line in the conclusion—that "STS has regularly shone the spotlight on 'things', but has taken relatively little interest in academic and professional identities" (p. 176)—underlines how far the authors have tried push ontological enactment as a replacement for epistemology. After all, the role of disciplinary, professional, and other positional identities in the contested construction of knowledge has long been the core concern of the history, philosophy, and social studies of science (e.g., Bijker, Hughes, & Pinch, 1987; Code, 1991; Galison, 1997; Geison, 1995; Longino, 1990; Schaffer, 1991; Shapin & Schaffer, 1985; Traweek, 1988). Balmer, Bulpin, and Molyneux-Hodgson have worked very closely with engineers, but despite labeling their informants with titles such as "Academic Environmental Engineer 1" or "Water Company Process Engineer 3," one does not come away with a good idea of what separates the two, or what makes them *engineers* and not *scientists*. The chapter on "barriers" is successful precisely because its more classically constructivist stance shows the actors' tensions, negotiations, differences, and compromises within the project, and this chapter is well worth seeking out on its own. For the rest of the book, the synthetic biologists, chemical engineers, R&D managers, environmental engineers, and their divisions and diversity are obscured by the authors' concerns about ontological categories whose relevance to their ethnographic subjects is never entirely clear.

[3] Water and sewage services were privatized in the 1980s by the Thatcher government, and the companies that make up the UK water and sewage industry are known for having a "conservative attitude toward innovation" (p. 42).

[4] The "ethical, legal, and social implications" program was originally an integral part of the Human Genome Project.

Similarly, in their discussion of the affective and embodied nature of synthetic biological knowledge, at the beginning of the iGEM project the sociologists note that they and their undergraduate charges became "clumsy … incompetent, novice [bodies]" in the laboratory (p. 128). Synthetic biology is not so easy that *anybody* can do it, and *A Sociology of Changing Practices* makes a very important point by showing how the iGEM team resorted to buying off-the-shelf resources from laboratory supply companies, rather than learning crucial techniques from the molecular biologists and other in-house experts (pp. 128–29). At the recommendation of the iGEM organizers, the undergraduates were essentially encouraged to outsource to equipment suppliers laboratory skills they lacked time or interest to learn. Exactly what skills, and what kind of equipment, Balmer, Bulpin, and Molyneux-Hodgson do not say. Instead they are deeply involved with the affective lives of their struggling iGEM team, and this particular post-ELSI collaboration leads them to conclude that "bodies remain in everyday practice, if not in its representation" (p. 141). It is certainly worthwhile to remember that knowledge includes implicit bodily knowledge of how to manipulate the basic instruments in a biology lab, but the difficulty of proper pipetting procedure or maintaining a sterile lab environment is not exactly news. iGEM teams and other synthetic biologists are replacing highly developed skills, practices, knowledge with equipment and parts from a catalog; exactly what kinds of practices and embodied knowledge are being replaced, and how widespread this trend is, *A Sociology of Changing Practices* does not say.

Whereas Balmer, Bulpin, and Molyneux-Hodgson focus on the periphery, Sophia Roosth's *Synthetic: How Life Got Made* tackles synthetic biology's core. *Synthetic* is an anthropological ethnography rather than a sociological one, and Roosth's fieldwork has taken her wherever her informants have gone, rather than staying at a single university site. Roosth follows Drew Endy, Kristala Prather, Tom Knight, Reshma Shetty, and other members of MIT's synthetic biology circle from Cambridge to Palo Alto and back, from 2004 up to 2015. Hers is a close-up, wide-angle study of synthetic biologists that tries to understand their perspective on both life and the act of creating it; it is neither a comprehensive look at synthetic biology, nor a treatment that is contextualized in the history of the life sciences more broadly. Rather than look at practices as Balmer, Bulpin, and Molyneux-Hodgson have, Roosth is after the *meaning* of life in synthetic biology—a question that many synthetic biologists demand we acknowledge through their constant repetition of Richard Feynman's apocryphal line, "What I cannot create, I do not understand" (see Keller, 2009, p. 295). "'Life' as an analytic object has come undone," Roosth writes (p. 8), and in fact "life" in *Synthetic* becomes a categorical and conceptual vacuum, one that sucks all of the actors in the book towards a collapsing and uncertain center. *Synthetic* holds together admirably even if it has a bit of a split personality, alternately seeking the changing meaning of life itself, and observing the synthetic biologists bringing about these changes.

But more on the meaning of "life" in a moment. Far more interesting is how familiar the economic and ideological facets in synthetic biology are, even as BioBricks™, standardization, and talk of genetic machines seem novel. *Synthetic*'s fourth and fifth chapters are inspired by David Nye's *America's Assembly Line* (2013), and Roosth's diagnoses of synthetic biological labor and the concomitant DIY-biology/biohacking movement in chapters 4 and 5 are the book's most insightful. It is yet another story of industrial automation, the deskilling of labor, the displacement of knowledge from people into machines or computers, and the social turmoil that results. Roosth asks the obvious question that everyone else in science studies seems to have missed: what happens if biotechnology really becomes as easy and as cheap as Drew Endy promised? Roosth discovered the answer when the students and professors she began following in 2004 moved on to Amyris and Gingko Bioworks, the synthetic biology startup in Boston founded by members of the MIT circle.[5] When Roosth visited Gingko Bioworks in 2012, an undergraduate intern showed her the fully automated biological assembly line, programmed with recipes for making all manner of custom microbes. He remarked that the system works on its own "without you having to think or make a mistake. It's quite powerful in that a user who has had minimal training in molecular biology can effectively do DNA assemblies that [otherwise] might take one or more trained PhD-level scientists to do" (p. 111). And from its beginnings in 2003, Amyris began "hosting competitions to see who was better at yeast strain engineering—humans or machines. The humans, it turned out, made more mistakes and worked more slowly. The robots performed in the competition eighty to a hundred times more efficiently than their carbon-based counterparts" (p. 119). As work with standardized parts became "repetitive and mindless," many of the biologists left, and those who remained at Amyris "decamped from the lab bench to middle management, where they are trained in a suite of skills for which they were not prepared in graduate school" (p. 118).

For Roosth, the stratification of the division of intellectual and physical labor in synthetic biology has elevated a handful of elite "designers" at Gingko and Amyris, while co-producing a growing crowd of DIY-biologists and biohackers. Roosth attended the meetings of such a group in Boston in 2008, and finds that they share the same hacking ethos that has a spiritual home at MIT. What Roosth describes as "crafty but innocuous" play is also permeated with a strongly libertarian, naïve political culture, purporting to champion a so-called "democratization" or "freedom" of biotechnology that Roosth is sharp enough to see through. "Such an optimistic, liberal, and liberatory reading is insufficient," Roosth argues, because

> their work is premised on the claim that the biological is not something cordoned off in labs but is instead quotidian, personal, and apprehensible. This is amateur biotechnology as a mode of political action, in which practitioners frame doing biological research as a right rather than a privilege conferred with a PhD (p. 139).

Roosth's argument about biology and biotechnology as a right is more descriptive than normative. By juxtaposing biohacking against her previous chapter on the deskilling and privatization of biotechnical knowledge, Roosth presents biohacking as a version of local food movements or home-brewing: literally-homegrown forms of resistance against mass production and automation, couched in the language of rights and freedoms, only in academic rather than food-industrial politics (p. 145). So far this conclusion seems sufficient, given that biohacking has been technically unimpressive and shows few signs of growing into a larger cultural phenomenon. The club that Roosth attended extracted and precipitated some cheek swab and oatmeal DNA using dish soap and contact-lens solution; it's an activity oriented more toward Instagram views rather than crowdfunding projects (cf. Eveleth, 2016).[6] But if the technology genuinely becomes as easy and widely available as Endy and other synthetic biology boosters have

[5] That is, Barry Canton, Reshma Shetty, Austin Che, Jason Kelly, and Tom Knight. Endy's earlier startup venture with Jay Keasling and George Church, Codon Devices, was launched in 2004 and closed its doors in 2009 (Hayden and Ledford, 2009).

[6] An October 2016 "Biohack the Planet" conference in Oakland, California seems to have drawn somewhere in the mid-double digits of participants; see https://groups.google.com/forum/#!topic/biocurious/J0ufiNTetKU (accessed 27 Jan., 2017). On the other hand, the Tech Museum of Innovation in San Jose, California, has just opened a new "BioDesign Studio," which encourages children and adults to try their hand at designing organisms; see https://www.thetech.org/biodesignstudio (accessed 21 Feb., 2017).

promised, then any ethical questions will likely land in the hands of multitudes of users, rather than the creators of synthetic biological technologies (cf. Bensaude-Vincent, 2013b).

These proto-ethical questions are made all the more complicated given how hard it is to agree on *what* synthetic biologists are creating, ontologically or phenomenologically. Luis Campos (2012) has tackled this issue before, in his essay on the legal and existential problems that surround BioBrick™ standard for open, interchangeable parts: a synthetic biological "part" that is interchangeable, modular, and decoupled from larger systems has proven to be an effective rallying cry, but a frustratingly difficult biological and legal entity to pin down. Roosth suggests a different reason for this lack of clarity: practitioners of synthetic biology have many opportunities to avoid such questions about their ethics or the nature of their creations, by arguing that they are merely solving problems using novel tools. Is synthetic biology about creating new species or new organisms? Or is synthetic biology merely the manipulation of enzyme pathways, or letters in a genomic text? One of Roosth's informants argues, perhaps in reference to *kashrut* laws, that "*nothing has pigness* or any other sort of species specificity, because genes can now be spit out of a DNA synthesizer rather than being sourced in a whole organism. By this logic, there is nothing particularly hybrid about a bacterium bearing genes culled from yeast, petunias, or Icelandic hyperthermophiles, because it is all just so many nucleotides" (p. 71). Roosth makes sense of this by demonstrating that such arguments thwart our instinct to draw the distinction between natural and unnatural (organisms, species, etc.), and she argues that the better analogy is to look at queer models of kinship as a meaningful guide: kinship not as so-called naturalized forms of relatedness like blood, genealogy, or descent, but rather kinship as being defined around care, sociality, and exchange. Conversely, we are related to and troubled by these organisms for reasons other than their chimeric genetic makeup.

This is a welcome interpretive and even ethical intervention, one Roosth makes herself as the writer and anthropologist, interpreting the minds and the contexts of her ethnographic subjects. Personally, I am skeptical that most of Roosth's informants would articulate such a nuanced, cosmopolitan point; to me, "it's all just so many nucleotides" is as sophisticated as saying that a brain is just so much carbon, hydrogen, nitrogen, and phosphorous. Roosth's book is full of examples of synthetic biologists busy making and creating life, though evidence of any deeper *understanding* of that life that synthetic biologists have created or the technical systems into which it will be injected is elusive—again, witness the dubious ontological status of the BioBrick™ part, accompanied by tweeted refrains of, "IANAL" ("I am not a lawyer," Campos, 2012). Synthetic biologists, Roosth argues, are convinced that "life is marked by the qualities—technical, substantive, and social—that they ascribe to it" (p. 10). In the ethnography, they are not doing much ascribing, and they seem interested not in what makes synthetically engineered microbes alive, but rather what they *do*. Nor does that seem to give this new generation of biologists pause: these intellectual, legal, and ethical challenges can be easily ignored or deflected with yet another fix or innovation. "Life" is not the issue to them; solving technical problems is. *Synthetic* is full of examples of synthetic biologists begging off epistemological and ethical questions in order to focus on what they do best, making things—an engineer's hubris most visibly displayed in Roosth's chapter on de-extinction research.

Who, then, is this synthetic biologist? I have to admit that the answer is still a little unclear to me. Endy's mid-1990s epiphany about biology's "unnecessary" complexity came after he had earned both an undergraduate degree in civil engineering (1992), a master's degree in environmental engineering (1994) from Lehigh University, and after he had spent time "fixing bridges" for Amtrak on the Northeast Corridor (Roosth, p. 25). What Endy learned as an engineer, what values he absorbed, what ideas he holds most dear from that formative period in his life, we never really learn, despite Endy's role as one of *Synthetic*'s key ethnographic informants. Nor do either of these books shed light on the intellectual or cultural distance between a range of engineering disciplines—civil, software, chemical, water, electrical—an especially important problem if indeed many synthetic biologists are coming from a variety of engineering specialties (cf. Ginsberg, Calvert, Schyfter, Elfick, & Endy, 2014). I think Roosth was not helped by the traditional historiography, which traces the history of a vaguely-defined "engineering ideal" in biology back to Jacques Loeb (Pauly, 1987), who never used that term or explicitly defined such an idea (cf. Campos, 2009, pp. 5–21; Keller 2009; Porcar & Peretó, 2014; Ginsberg et al., 2014). Phillip Pauly (1987) used the expression "engineering ideal" to describe Loeb's desire to create and control living matter, but Pauly wrote little about how (or whether) Loeb thought about engineering itself, part-whole relations, homologies across phyletic groups, the autonomy of cells or genes, standardization of laboratory techniques, analogies of life to circuits, or the process of making-as-such. The historiography of biotechnology has been growing rapidly in recent years (e.g., Landecker, 2007; Curry, 2016; see Charnley, 2016); we are only beginning to get a better grip on how today's engineering ideals and bioengineers came to be.

Perhaps Endy, Benner, and Sismour's prophecies from 2005 missed the mark entirely. In the wake of the Human Genome Project, the cost of both sequencing and synthesizing DNA dropped so precipitously after 2006 (NHGRI, 2016; Economist 2006) that storing cloned genetic parts may never have been necessary to usher in a new age of biological engineering. After a lackluster IPO in 2010, Amyris is now saddled with debt and is trading as a penny stock (Grushkin, 2012), while as of 2016 the only product Ginkgo Bioworks publicly advertises is a prototype rose oil made in partnership with the fragrance company Robertet.[7] Roosth briefly mentions that the CRISPR/Cas9 technique of direct genome editing could well turn synthetic biology's talk of interchangeable genetic parts into a historical footnote (p. 172). And there is a sense in which synthetic biology's radicalization of the genome-as-code metaphor is outdated, now that biologists' attentions have shifted towards the epigenome, microbiome, and other -omics.

Be that as it may, synthetic biology has now sharply drawn our attention to the power that biological engineers wield, and not only over the lives synthetic organisms. Like the idea of the assembly line, synthetic biology seems to be new engineering ideal that has amorphously taken shape through a concatenation of ideas, techniques, material changes, economic conditions, and cultural trends, championed by odd individuals with uncanny insight, force of will, or both (Nye, 2013, pp. 3–4). We need a better understanding of this concatenation's historical genesis. What we lack now is not a better understanding of what life has become, but rather the biological engineers who have learned how to work with living microbes and tissue cultures as materials without needing to deal with their liveliness (Landecker, 2007). As with the case of the assembly line, the new biological engineering might well be a technological system for which we will never have a clear perspective; David Nye notes that we did not even begin using the phrase "assembly line" for at least two decades after that technological system had been invented at Ford (Nye, 2013, pp. 43, 257–8). I would not go so far as to say that we are all synthetic biologists now—but for decades we have been living in the age of synthetic biology, whether we have had a name for it or not.

[7] http://www.ginkgobioworks.com/our-work/, accessed February 2, 2017.

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