A THEORY OF TRANSFORMATIONS

Earle McCartney

1. The Manson Disturbance

I SPENT MUCH of breakfast staring out the window, trying to distract myself from the coming day's work, from the hours I'd spend struggling with our transformation. The view was of our street, its identical townhouses marching uphill to the neighborhood park, a grassy rise dominated by a single, ancient, enormous tree. The tree calmed me. Looming from its hilltop, it seemed as cut off from my worries as a galaxy viewed through a telescope. I didn't know what kind of tree it was. I asked Marshall.

"I don't know trees," he said, not looking up from his book. I studied his face—the square jaw, the downturned mouth, the eyebrows that always meant business. He seemed to be hard at work solving a thorny problem. The ponytail only heightened the effect. It made him look like a humorless young academic. I caught him running his finger along the lines as he read and had to look away. He stopped to take a sip from his coffee and caught me

staring out the window. "I wouldn't have thought I could be jealous of a tree," he said. "Yet here we are."

"I'm serious. I thought you would know. Why did I think you would know?"

Marshall shrugged. "What can I say? I'm a mystery."

"What are you reading, anyway."

"Geology," he said. He closed the book around his finger and held it up for me to see. An introductory college text, from the look of the glossy cover. Maybe high school.

"I have to go to work," I said.

"Don't forget your calculator."

Did he realize he'd made the same joke the day before? Maybe because I hadn't laughed, he'd thought I hadn't heard. Fair enough. I wasn't always good at listening.

That night Marshall brought home another library book, the Audubon Society's *Field Guide to North American Trees*. "It's an elm," he said. "Be happy."

My team's task was to construct a lightly mixing continuous transformation (i.e., a lightly mixing flow) over an infinite two-dimensional measure space. Using a modified version of a known lightly mixing non-continuous transformation, we'd built a flow that operated on a one-by-one square to which we'd appended a series of smaller rectangles, the sum of whose areas was unbounded. The heart of the problem, then, was to prove that our flow was lightly mixing. This was all straightforward enough. The project involved some

intuitive geometry, made for interesting pictures, and seemed doable over the course of a summer—the key advantages listed by Kovács, our facilitator, the day we arrived. There hadn't been much work done with flows, he'd said. The field was wide open. It was just a matter of translating from the discrete to the continuous. But I was stuck.

I went looking for my group and found Noah horsing around in the computer lab with Knot Theory and Soap Bubbles, Casper asleep in the library with his notebook tented over his face. As usual, I met with Kovács on my own.

Kovács sat with his back to the door. He pointed a camera out the window and gently rotated the barrel of its lens. A tree—another elm—blocked the view.

"What are you looking at?"

"Oh!" He set the camera on his desk, embarrassed that I'd caught him in an idle moment. "The leaves are very pretty."

The drooping clusters stirred gently in the breeze. "They are pretty," I agreed. As the breeze picked up, their stirring became larger and more coordinated.

Kovács was oblivious to awkward silences. During meetings he'd sometimes sit for minutes at a time with his eyes unfocused, looking thoughtful and content. I took a seat and folded my hands in my lap. The drawings from one of our first planning sessions still filled his blackboard, all crescents and loops and stacked rectangles.

He noticed me again. He set the camera on his blotter, in front of his neat array of family pictures. He rested his fingers on the edge of the desk.

"So," he said. "How are things going?"

"Things are going fine," I told him.

"The approximation?"

He started tapping a finger. He wasn't worried, just impatient—he wanted me to talk to him, to make him feel properly involved. It was our reason, I thought, for having these meetings: so he could hear that his help was unnecessary. I assumed he thought the project was trivial.

"We're close," I told him. "I'm tweaking it. A few more read-throughs and I'm sure we'll be there."

"Okay!" Kovács said, pushing back from his desk, finished with business. "And Marshall?" He'd met Marshall briefly at the Memorial Day potluck and had made a point of remembering his name.

"Marshall's fine," I said. "He keeps himself occupied. Apparently he's getting into geology."

"Wonderful! This is a good area for Devonian formations."

"I'll tell him."

"And Noah and Casper?"

"Working hard," I said.

Kovács laughed. "It seems they've elected you prime minister of Ergodic Theory."

I thought, *That's terrific.*

Just then, Noah came rushing up to Kovács's doorway.

"Speak of a donkey," Kovács said, "and it shall appear in

the garden."

Noah knocked on the open door and said, "Did I just miss a Hungarian proverb?" He apologized for being late, as if it were the first meeting he'd ever missed. "Any news?" he asked, and before we could say no, he said, "I was talking to some of the other groups. Knot Theory says they're onto something."

Kovács raised an eyebrow.

"They always think they're onto something," I said.

"But this time they *really* seem excited. They say Clark has come up with a new approach."

Clark did all the heavy lifting in Knot Theory. He'd taught himself calculus at age twelve, had entered college at fifteen, had been published at seventeen. He also played the harpsichord, tracked spy satellites, and raced motorcycles.

"Clark doesn't impress me," Noah was saying. "He's no Lucy, right Kovács? Our secret weapon!"

"Secret weapon's the wrong analogy," I said.

"Okay, then—our doomsday device."

I didn't laugh. They didn't expect me to.

Afterwards, as I passed through the library, Graph Theory looked up from their notepads to frown at me. Casper was still asleep on the couch. He'd started snoring.

In our group—the program's smallest—the work had quickly been divided. Noah and Casper were working on the lemmas we needed. (Casper thought it funny to call

them lemons.) Noah also took it upon himself to TeX up our argument's finished components, readying them for publication. (This was also his excuse for loitering in the computer lab.) I had very swiftly mastered the terms of our project (and had been published, as a co-author, once before), so from the beginning, my teammates had deferred to me to grapple with the center of the problem.

In the back of one of the basement classrooms, I'd found an old wooden table and a wheeled office chair. This was where I preferred to work. While seated there, I could lay out Bill Metzger's well-known proof—the one that provided the foundation for our approach—and spread beneath it the pages of my own thinking. Then I could roll up and down the length of the table, examining the steps in my argument—or, more often than not, pretending to examine them. With every day that I spent struggling, I found it harder to stay on task. I spent a lot of time working at working, instead of simply working. Or working at working at working, *ad infinitum*.

After a single knock, the classroom's door swung open. It was Clark. I gathered my papers into a pile. He closed the door and walked directly down the center aisle, dividing the room in two.

"Knock, knock," he said. "I was looking all over for you. Is this where you hide?"

"Not any more."

He sat on the edge of the table and looked around my little room. "How do you work in here?" he said. "There's

no window."

"I like the isolation."

"I can't get anything done without a window," he said, ignoring the hint. "How's the fiancé?" he asked. "What's his name again?"

"Marshall's fine," I said, put off by the question. I realized that I hadn't thought of Marshall since I'd left the apartment that morning.

Seeing the tangle in my expression, Clark narrowed his eyes and nodded. I wished he'd quit nodding. Finally he glanced at my papers and waved his big open hand over them, the way a magician might. "How's Ergodic Theory?"

"Coming along." I nudged at the edges to tidy up the pile.

"Close to the vest—I like it." He boosted himself farther up on the table, closer to my side. "What does 'ergodic' mean, anyway? I know the technical definition—but where does it come from?"

It hadn't derived naturally from anything—Boltzmann had made up the name using the Greek words for "work" and "path"—but to admit that to Clark would have somehow felt self-deprecating. Instead, I said, "It's complicated."

Clark smiled. "Are there any practical applications?" he asked, imitating a layperson's suspicions.

"The act of stretching and folding dough," I said, "does a good job of moving raisins around." I let myself laugh a little. "We call it the Taffy Transformation."

"Nice," he said. "I'm sure bakers find it fascinating."

"My father's a baker."

Clark looked skeptical, thinking maybe I was kidding him. Clark's father, I knew, was a well-regarded classical composer.

"Now I feel like a snob," he said, searching for a window to stare out of.

"Well," I said, "you should."

He caught the note of friendly mockery and smiled, displaying his perfect collection of straight white teeth.

"Clark, what are you doing here? Did you come to gloat?"

Now he looked mildly hurt. "I can't stop by to chat? I can't just be friendly? We could all be more collegial around here."

He was right, of course. The program often felt like arena combat. "Look, I'm sorry."

He waved away the apology and pressed his long, chalky finger into my stack of papers. "I had an idea last night before bed," he said.

"So you do sleep."

"You know," he said, "the rumor is you're full of interesting insights. Maybe we could put our heads together."

"Clark," I said, and then stopped, unsure of what he was suggesting. "Are you asking me out?"

"Just being collegial."

"I'm not sure it's in my nature to be collegial."

"You'd rather be rivals."

"Keep going."

"Mortal enemies?"

"Now you're getting it."

He threw his head back to laugh. His breath smelled like coffee and lifesavers. There were voices in the hallway.

"Uh-oh," Clark said. "I've given away our position."

The doors to the neighboring classroom clanged open and shut. Clark's name was being sung: *Cla-ark*. He stood up as our door opened. It was the twins from his group, the only other women in the program. They dressed like they had something to prove—kohl eyeliner, low-cut blouses, six-inch heels. I'm the kind of person who's good at vanishing in crowds. Makeup gives me a rash. My wardrobe features many shades of brown.

"There you are!" the twins called out.

"Here I am," Clark replied.

"Charlie needs help with his lemma," they said.

"I'd better rescue him."

They looked at me. "Clark," they said. "You're making us jealous."

"Ladies, please. There's plenty of Clark to go around." He put his arms around the twins' shoulders, and as they left he flashed me one last roguish smile.

With the room empty again, the buzzing of the fluorescent lights seemed to have gotten louder, as if Clark's outsized presence had jolted something loose. I spread my papers, took a breath, and tried to concentrate. I tried again to visualize what Kovács called the crescents—the pieces

our sets evolved into as they were moved around by our flow. Continuously more numerous, ever smaller crescents, falling through our measure space. I couldn't manage to show that the crescents had to be touching. Crescents? Not crescents, more like sickles. Crescents, sickles—what's the difference? Work, Luce, work. Forget Clark. Forget everything. It wasn't working. *I* wasn't working. I was staring at my argument and waiting for a new idea, suspecting that something was wrong.

Marshall made dinner, and I pretended to enjoy it. He'd baked a loaf of sourdough bread stuffed with capacola, mozzarella, mushrooms and olives. He lit candles and poured himself a glass of wine. I was having trouble forgetting my day, so I decided, for a change, to have a drink with him. I got a mug from the kitchen. Marshall poured.

"So," he said, offering me a hopeful look. "How was your day? Any progress?"

I set down my half of the sandwich. I preferred not to think about work while at home. I had told him many times.

"I can't never ask," he said. He leaned back in his chair and crossed his arms behind his head. "But okay."

I picked up my sandwich again. "How was the deli?"

"Tiring. Let me tell you about quartering chickens. Turns out it's not as simple as you'd think."

Part of me wanted to tell him I was in trouble. I watched his mouth as he spoke, and I wanted to touch his lovely, awful whiskers and tell him I was failing. But assume I did. If I told Marshall I wasn't making progress, then I'd have to admit to myself that I needed a new approach, which would mean telling Kovács, and then Noah and Casper. Inevitably, everyone would hear. Knot Theory would hear. Which I couldn't allow. Q.E.D.

"I can tell you're not listening," Marshall said.

"I'm sorry."

"You look tired."

"I am tired."

"I can't wait for you to be done here."

"Me neither," I admitted. "You know what happened? Clark Dybczak made a pass at me."

"What?!" He looked more intrigued than offended. "That must have been awkward."

"Yes," I said, sipping my wine. "It was."

"What did you say?"

"What do you think? I told him to go bother someone else."

"I wish I could have seen your face. What was he thinking? Is he suicidal?"

"Marshall," I said. "Don't be mean."

Marshall looked chastened, yet still amused. We drank our wine. I finished mine.

"Tell me about what you're reading," I suggested, to change the subject.

"More geology. Did you know," he said, "that we're living near a major geological oddity?" He leaned forward as he described this thing, this "Manson Disturbed Area," that he'd read about in another textbook. Something about core samples and Precambrian rock strata. The strata were disturbed, had been fractured and mixed together. Strata made me think of the stacked steps in our measure space. Maybe a different shape for the steps. That was a new idea, right there. Bound the additions under a curve or something. Would it matter? No. You'd always end up with sickles.

"A cryptovolcanic event," Marshall was saying. "An upwelling of magma."

"Cryptovolcanic," I said, forcing myself back into the conversation. "That doesn't sound right."

"It's right," he said, bristling.

"It sounds like hand-waving."

"No, look," he said. He went to the bedroom and got the book. He handed it to me with his finger pressed to the word.

I flipped to the title page. "Marshall," I said, "this book is forty years old."

"It is?"

"Geology is not a dead language."

"Well, what's the difference? What's the matter?" When I didn't answer, he said, "It's weird, whatever it is. I'd like to visit it."

"I can't just take a day off for a field trip."

"Maybe I'll go by myself."

"Don't be like that."

"Like what? Jesus Christ!"

I poured myself another mug of wine. "I'm sorry," I said. "I don't know how to act right now."

"Okay," Marshall said, always too eager to move on. He reached for the wine and filled his glass halfway. "Let's start this over. Try to listen. Quartering chickens—"

I tried to listen, I really did. But I was tired, and worried, and being worried made me restless. The wine didn't help. Somewhere in there, he lost me.

2. The Genesis Program

Casper was younger than the rest of us. A last-minute replacement for a Lebanese woman with visa problems, he hadn't applied for his spot in the program. Instead, he'd been shooed in by his thesis advisor, one of the program's founders. The rest of us had each beaten out fifty to sixty other applicants for our positions, while for him the program was a lucky summer job. It was exasperating to realize how much he took for granted, how little he seemed to care. But it was also fascinating.

"Sorry to interrupt," I said, taking the seat across from his couch. He was staring out the library's big picture window with an empty notebook open in his lap. "I see you've clocked in."

Casper nodded, impervious to sarcasm. "I can't think without a window."

"That's what Clark says."

"Then never mind. I can't think without an empty notebook—that's what I meant to say."

He started tapping his pencil on his notebook, nodding along to whatever soundtrack he had playing in his head.

"Is the lemma going to work?" I asked.

"What lemma."

"The one I gave you." He continued to tap his pencil. "The Metzger one, the one I asked you to convert for flows." Casper raised an eyebrow. "The one I absolutely have to have in order for our proof to work!"

He smiled. He was baiting me. "I prefer the term lemon," he said.

"That is no longer cute."

"Okay, okay," he said. "Right. That lemma."

He flipped through the notebook, pretending to look for his work. I thought: He'll regret having wasted this opportunity. Then I thought: No, he won't.

"Don't get angry," he said.

I wasn't angry. Anxious, frustrated, but not angry. "People always think I'm angry when I'm not."

"It's because you never smile."

He was right, of course. I don't have a good face for smiling.

"Casper."

"It'll work."

"You're sure?"

"Yes, yes, yes," he said. "I did it last night. It's stupid."

I allowed myself to be cheered by this glimmer of competence. Then he leaned back on the couch and propped his dirty boots on the coffee table. The cuffs of his pants were stiff with dried mud.

"Where have you been?"

"What are you, my mother? I took my dirt bike for a ride before lunch."

I closed my eyes and leaned my head on the back of my chair. "We are getting paid to work here."

"I'm not getting paid enough."

It must have made things so easy for him, not to care.

"I'm sorry," he said, sounding halfway sincere.

"I can't do this by myself," I said. It was a big admission to make to him. I listened to the sound of his feet being lifted from the table, then the brush of his palm sweeping up bits of dirt.

"You think too much," he said. "It'll be fine."

"That's why we're here," I said, rubbing my eyes hard with both palms. "We're getting paid to think too much. We're supposed to enjoy it."

I took a deep breath. I heard Casper fidgeting. It was a new kind of fidgeting. I opened my eyes and there was Clark, sitting on the couch's arm.

"Where the hell did you come from?"

"From your classroom," Clark replied. "From everywhere! I've been looking for you."

The leather upholstery squeaked as Casper shifted. He was very obviously working hard to keep himself from openly scowling.

"I just wanted to let you know," Clark said, "that I'm having a party next Friday."

The other groups often threw parties on the weekends. I never went.

"Should be exciting," Clark continued. "We're hoping for the groups to give informal presentations of results. Collegiality!" He waited for a response; not getting one, he went on. "Knot Theory will go first, of course. There'll be pop and ice cream."

"Sounds like a blast," Casper said.

"It will be! Especially if you can come," Clark said, shooting me a look.

"Clark," Casper said, "could you please go away? Can't you see that we're working?"

"Okay, okay," Clark said. "Sorry to interrupt. But please come."

Casper twisted around to watch Clark go. "Pop and ice cream," he said, shaking his head. "I'll make sure to bring my flask."

"You're my hero," I said. "Do you know that?"

Casper smiled. "How is our work going, anyway?"

"Not well," I said. I imitated one of Casper's what-the-hell shrugs but found no comfort in the gesture.

The prospect of failure was disorienting. I'd gone out of my way to find a new challenge, in a new place, with new people. I'd seen it as a test, of course, but one that would affirm my grandest secret vision of myself—Lucy Hawkinson, reclusive genius!—not one that would expose my limitations. I'd never failed a test in my whole life.

I intensified my efforts. So that no one would know where to find me, I spent each day in a new classroom, leaving only when a janitor came to empty the trash or wash the blackboards. At home, I worked late beneath a desk lamp I'd moved from the bedroom to the kitchen table. Marshall never complained. If he got up to use the bathroom and found me asleep on top of my notebooks, he'd slide the pencil from my hand and gently walk me to the couch, so that if I woke up with a new idea I wouldn't be far from my work.

The day before Clark's party, Noah found me in the basement auditorium. I'd requisitioned a projector and was using it to reexamine the steps in our argument: (1) run the transformation; (2) approximate the measure of the sickles; (3) run it again, until our approximation reached the needed proportion (Metzger's Double-Approximation Property); (4) approximate the measure of the total intersection; (5) Double-approximate *again*, and continue thusly until the measure of the intersection must be nonzero. It was starting to seem like too much approximating.

Noah came in wearing a T-shirt with the name Luci printed on it. Underneath the name was a picture of some

kind of armored robot. Noah saw where I was looking. He touched his chin to his chest, then looked up, worried by my expression. "Didn't I tell you about Lucifer?"

Now I remembered. Casper had told me that Noah and the others had been killing time designing virtual creatures in the computer lab, part of some online project modeling predator-prey ecologies.

"We named her after you," Noah added. "She's ferocious."

"Noah," I said. "What exactly is my reputation around here?"

"Your reputation," he said, smiling.

"Don't answer," I said. "I know. I'm the bitch of the program."

"I wouldn't go that far."

"It doesn't bother me," I told him. I waved at the shirt. "I'm honored."

"She's killed and eaten seven of Soap Bubbles' critters already. We're very proud of her."

Okay, I thought. This is what Noah does all day, his way of avoiding acknowledging our impending failure. I nodded along, distracted, wanting to get back to work. But Noah was sensitive. He could tell I was dismissing him. For a moment, he looked hurt. He lifted a hand to his beard and gazed up at the projector screen.

"Any ideas?" I sighed.

Noah shrugged. His arms looked skinny. The T-shirt, I realized, was too big for him. Maybe he'd put it on just for me.

With a look like he'd suddenly remembered something important, he set his satchel on a chair, unzipped it and dug around inside. He handed over a manila folder. "The illustrations you requested." He reached in again and pulled out a bundle of cloth. He flapped it open like a towel and presented it to me. It was another Luci T-shirt.

"We're wearing them to Clark's party," he said. "We must strike fear in the hearts of our enemies."

I folded the shirt so that the picture wasn't showing. "Thank you, I guess. I'm sorry."

"Right," he said, stroking his beard. He looked confused. He sat down. "Sorry for what?"

"For wasting your time here."

His eyes widened with genuine, affectionate surprise. "Are you kidding? This has been the best summer of my life!" He tapped me on the arm. "I've learned so much. And you're doing great. There's still time. Believe it or not, I'm almost done with my lemma." He jumped out of his chair, said, "Back to the grindstone," and jogged up the steps to the exit. The cheerful sound of him hitting the panic bar rang through the empty auditorium.

I went back to the beginning and once again inspected my argument, step by step. There were no mistakes that I could see. The approximation simply wasn't good enough. I twisted the projector's focal knob until my writing was as illegible as homework dropped in a puddle. Then I opened Noah's folder. I slapped the first slide of graphics onto the projector, adjusted the focus and was astonished.

It was lovely the way he'd pictured it, with the sickles from different stages dispersed across the space and color-coded into reds, yellows, and oranges. The second transparency showed our flow in advanced development—all stages and scales superimposed in overlapping colors. The third zoomed in to show the final, fictitious step in our transformation, the one my team was counting on me to produce, where the tips of the blades of two red sickles intersected.

The next morning, I finally asked my teammates for help. I sent them an email saying I'd been going about revision all wrong. It was a mistake, I'd decided, to treat each step as a discrete component. I said I wanted to show them the proof all at once on a blackboard. Maybe we could fix the thing together.

I expected to have to round them up and drag them by the ear, but instead they both arrived for the meeting ten minutes early. That they took me so seriously was both touching and terrifying. We met in my little room with the oak table, the one where I'd done my best thinking at the start of the summer. Casper sat on the table, and Noah wheeled the rolling chair next to him.

"It's like a closet in here," Casper said, looking around nervously, as if he didn't trust the walls not to close in even further.

"There's lots of board space," I said. All four walls featured

a good-sized blackboard.

"Is this what the inside of your brain is like?"

Noah laughed. "I'll bet it's like the Grand Canyon inside Casper's head."

"It is breathtaking," Casper said, "being Casper."

"Boys," I said.

They gave me their attention. I opened a new box of chalk and began shaping our argument. As I continued from blackboard to blackboard around the room, I kept expecting one of them to interrupt me. Pensive, considerate Noah might say, "Well, wait, maybe I'm wrong, but can't we improve on that?" Or quick, undisciplined Casper might stand on the table and yell, "Hey, I see it!" But instead, they let me continue until I'd reached the end, having filled all four blackboards. There was chalk on all the fingers of my right hand. There was chalk on my pants and on my sleeves. My nose itched; there was chalk on my nose. I set the nub of chalk in the tray and looked to my teammates. Noah smoothed his beard. Casper wore a neutral expression that I immediately found concerning.

"Yup," Casper said. "We can't do that."

The "we" was a kindness on his part. The moment I looked where he was looking, at the third panel of the fourth chalkboard, I saw what he saw.

"Can't do what?" Noah said. "Oh, wait."

It was so stupid. I'd never looked at the beginning and end of the argument together—there were so many steps in between. The problem was much worse than I'd realized,

not just that the proof was falling short, but that it was *wrong*. Of course, of course, of course, of course, of course.

"We assume a delta here, as we start to run the transformation," Casper said, turning halfway around to point to the first blackboard, "and then we take another delta here, when we decide if we need to iterate. We assume the first delta based on how we know the flow will act later. We assume the second based on how it ran before. We're going in circles!"

My hands were sweating. I wiped my palms on my jeans and left two fat white streaks across my thighs.

Noah volunteered to get Kovács.

Kovács stood with his hands on his hips and smiled as he read. He nodded at the end and said, "No, this will not do. How about that?" He looked at me differently than he had before, as if from a greater distance. They were all so surprised.

"Okay," Kovács said. "I will call Bill Metzger. We have time. Maybe there is something we can do."

I walked to the board and started erasing. Up and down, slow strokes. Kovács could tell I was upset. "Try not to feel bad," he said. "There is more to life than what happens on a chalkboard."

I didn't reply. I didn't need to be patronized. He left looking embarrassed. The door closed behind him, and we stared at it. We stared and stared. Maybe I was the only one staring. Casper and Noah waited for me to speak, God bless them.

"Well, shit," I managed to say.

They laughed gratefully. Casper reached into his hip pocket, brought out a dented pewter flask and unscrewed its cap. I took a sip and offered it back.

"It's a special occasion," Casper suggested.

I drank. It burned.

The deli stayed open late on Fridays. I sat alone in the apartment after work, trying not to think, still buzzing from Casper's whisky. The living room seemed to have gotten smaller. When Marshall and I had moved in, I had argued against hanging pictures since we'd be in Iowa for only a summer, and now the bare white walls were like empty sheets of paper hemming me in. I decided to go to Clark's party.

The windows of Clark's duplex were warm yellow rectangles in the blue dusk. I heard laughter as I approached. On the porch, the guys from Algebraic Geometry were smoking cigars, trying unsuccessfully to blow rings. I waved and they waved back. I heard one of them say, "I'll be a monkey's uncle." I smoothed my blouse against my stomach and went inside.

Casper and Noah seemed happy to see me, although Noah complained that I'd forgotten my Luci T-shirt. (Casper had forgotten his, too.) A blackboard, projector, and screen had been set up in Clark's living room. I speculated that maybe they were always there and got a laugh. Casper brought me

a Styrofoam cup filled to the brim with white wine—so there wasn't only pop—as Soap Bubbles began describing their limited results.

As I finished my second drink—another dose from Casper's flask—I felt my affection for my teammates growing. Noah's presentation of our project was engaging and confident. Of course, I thought, he is a people person. He showed his lovely pictures and explained accurately, but only in the most general terms, what we hoped we were possibly on the verge of maybe accomplishing. It was hard not to laugh at Noah's audacity. I elbowed Casper, and he did his best not to smile.

As we applauded, Noah raised a hand to quiet the room. "I have something to add," he said. "I'd like to announce that our precious Lucy"—I felt my heart seize up in terror, until he slapped a new transparency onto the projector—"that our precious Luci is pregnant." Beneath the picture of Luci was an array of smaller killer robots. "Be very afraid! The Genesis Program will soon be ours!"

More applause. People lifted their cups, making a show of congratulating me.

I put my arms around my teammates. "I love you guys," I told them.

"I hope you didn't drive," Casper said.

"But seriously," I said. "You guys are the best."

They started to look embarrassed for me. It wasn't just the alcohol. They could see that I'd been thinking, "Okay, then: *camaraderie*." They looked uncomfortable with the

new Lucy. Who knew what she might do next?

Noah latched onto Graph Theory and helped them network a bunch of computers for some kind of tournament of predators. Casper started dancing with the Knot Theory twins. I stood at the edge of numerous conversations, unable to mix in. I wandered into the kitchen with the feeling that I was looking for something. I found Clark. His teeth came swimming across the room. He handed me a cup filled with red wine. I downed what was left of my whisky and sheathed the new cup in the old one.

He nodded back at the living room, toward the empty screen. "Impressive work," he said. Maybe he meant Luci, but I thanked him anyway. His sneakers were bright white. I took a gulp of the wine. It tasted like pennies.

"Where's your boyfriend?" Clark asked.

"Marshall."

"Where's Marshall?"

"He couldn't get off."

"What's he do?"

"He works in the deli-bakery on Church Street."

Clark cocked an eyebrow. "You've got a lot of bakers in your life."

"He used to work for my father."

"Interesting." Clark had a very pronounced Adam's apple. It bobbed as he drank his wine.

"Let's not talk about Marshall," I said.

Clark looked down at me and frowned. It was a happy frown. "You know," he said, waving toward Noah, "that

Genesis thing is doomed."

I nodded like I agreed completely but said, "Why's that?"

"Everyone's making predators," he said. "No one wants a herbivore. And now the predators are all having babies." He smiled a gleeful, homicidal smile. "I predict mass starvation. Or even better—cannibalism."

"Poor Luci," I said. "Just as she was coming into her own. It's tragic."

"Is it?" Clark's teeth seemed to be getting larger.

I finished my wine.

"You missed my presentation," Clark said.

"I guess I did."

He reached over and touched my hair. I flinched, then touched the hand touching my hair. Clark's skin was cold. Marshall's skin was always warm.

I WAS VERY late getting home. Marshall was asleep. I sat on the edge of the bed, watching the blanket swell with his breathing. He looked so helpless. I shook him.

"Hmm," he said, turning towards me. "How was the party?"

"Marshall," I said. "Wake up."

He blinked at the clock. "You must have had fun."

"I didn't," I said. "I swear to God, I didn't."

He turned off the lamp, and in a small voice he said, "I don't want to know."

"I have to tell you."

"Don't do this! I don't want to know!"

He cried more easily than I did. It hurt me to hurt him, it really did. But as I pressed my face against his back and we lay quiet in the dark, I felt like there was something missing from what I was feeling. He was ready to forgive me already, and I hadn't even said that I was sorry. That's how scared he was. After he fell asleep, I took a shower. I buried my blouse and my underwear at the bottom of the trash. I stared at the white walls, at the cracks in the plaster. I was exhausted. I was disoriented. I was miserable. It was a problem.

3. Rank One Infinite Measure Preserving Transformations

I GOT UP one morning a week later to find that the tree outside our kitchen window, the one that had seemed so permanent and mighty, was gone. I walked up the hill to see what had happened. I'd been living in this development at the edge of town, close to where the streets hit the corn, for almost three months. Yet this was the first I'd ever gone for a walk, the first I'd noticed how perfectly uniform the neighborhood was. I passed block after block of identical yellow duplexes, cheap housing for transient students. Stopping at an intersection was like standing between two mirrors; looking either way, I found myself staring down a bottomless pit of infinity. My tree had seen a lot of changes. Now it was wood chips.

The stump was wider than the span of my arms—it would have taken four of me holding hands to encircle it—and its surface consisted of two uneven planes, two cuts that had failed to meet. Standing in the grass nearby was a sign for a landscaping company. They'd done a thorough job cleaning up. Nothing was left but ragged leaves, twigs, a few small mounds of orange sawdust.

"They killed my tree."

Marshall looked up from his coffee with no expression. Which of course was an expression. "It's been gone since Tuesday," he said. "I'm surprised you didn't notice."

I poured myself a glass of water, to have something to do with my hands.

"The crown had lost half its leaves," Marshall added. He raised his voice because my back was turned.

I sat across from him. His hair was a mess. A grain of sleep was suspended in his eyelashes. The sun came out, projecting between us an orange beam of light swirling with dust. Marshall frowned and turned a page of his book. Then the sun went in, the color faded, and the air seemed still again.

"I should have counted the rings," I said.

"It was old," he assured me.

"It's funny," I said. "I'd assumed Dutch elm disease was a thing of the past."

"Yes, funny." He turned another page, afraid to engage. "Trees can die for many reasons." He sipped from his mug and made the affected wincing gesture he made whenever

he wanted what he'd said to seem extra significant.

"Don't be dramatic," I said.

"Just a statement of fact."

"I was only teasing," I said. "Never mind. I have to go to work."

"I know." He shrugged. "So do the rest of us. I'm sad for your tree."

Was I sad? I didn't think so. I'd used Clark to gouge a space out of myself, and whatever had rushed in to fill that space, it wasn't sadness. Same with the tree: the shape of its absence—the smell of the sawdust, the roughness of the cut, the flattened grass where it had fallen—was more real than its presence had ever been for me.

Bill Metzger came to town at Kovács's request. Old friends, they'd roomed together as undergrads and had done their doctoral work together under Chacon. Many of Kovács's papers listed Metzger as a co-author. According to Kovács, Bill Metzger had written the book on lightly mixing transformations. If he couldn't help, then nobody could.

Casper and Noah dragged chairs in from the library as Metzger sat on the edge of Kovács's desk and skimmed my manuscript. When he had finished, he handed the papers to Kovács. "You didn't tell me you were trying flows," he said.

Kovács smiled, embarrassed.

"You've done a fine job of adapting my transformation," Metzger said, turning to the three of us. "But as-is, the approximation doesn't work for flows." He tapped his chin and squinted at the wall behind my head. "Which is interesting." He approached Kovács's small blackboard, lifted a long, new piece of chalk from the tray, and with one hand in his pocket drew a set of wavy vertical lines. Then he turned and began explaining some kind of "ergodic string approach" he'd been thinking about. Kovács looked at us from behind his desk and shrugged. We had only three weeks before our manuscript was due. "Oh, well," Metzger said when he had finished. "I suppose that isn't helpful." He set the chalk back in the tray and lifted his fingers to examine the dust, front and back. "The hazards of mathematics."

Kovács offered him a tissue.

Still wiping his fingers, Metzger asked Kovács what he was thinking.

"Oh," Kovács said, "I don't know. A return to transformations is probably in order."

Metzger, offering no sign of having heard what Kovács had said, handed back the used tissue and waved at the row of pictures on the desk. "How's the family?" Not waiting for an answer, he unbuckled his leather satchel and came out with a large camera case. "Look what the kids got me," he said.

"What an asshole," Casper whispered as we left.

"Metzger?" I shrugged. "What else did you expect."

"No," Casper said, "*Kovács*. Guy couldn't care less about our project."

"I'll bet he's got something up his sleeve," Noah said.

"Wishful thinking. You watch."

I noticed Knot Theory working at the other end of the common area, marking up a printout of something, no doubt their nearly finished manuscript. Clark and I hadn't spoken since the night of his party. I'd been ignoring his emails and phone calls all week. I reached the edge of the lounge and stopped. Marshall was standing by the entrance, not twenty feet from Knot Theory, looking lost.

"Isn't that Marshall?" Noah said. Marshall heard his name and saw us. He walked a few steps toward us, but then said, "Oh," and turned to retrieve the paper bag he'd left on top of the information desk.

I noticed Clark glancing up from his work.

"Hey, Marshall," Casper said. They shook hands and examined each other in that way that men do. After he and Noah had gone through the same ritual, Marshall looked me over.

"You're all red," he said.

"What are you doing here? How did you find the library?"

"I can read a map. And once I'd found the building, I followed those jokers." Marshall waved a hand at Knot Theory. "They seemed adequately brilliant."

Casper laughed out loud, and Clark glanced at us again. Casper and Noah exchanged looks.

"So," Marshall said, looking from face to face. "Where's this Clark I keep hearing about?"

"I think he's at lunch."

Noah and Casper drifted a step away from me. They tried not to look at Clark, or at each other, or at me, or at anything.

"You may not have known this," Marshall said to them, "but Lucy is the world's worst liar." He repositioned himself with his back to Knot Theory, so I could see that he knew. With both hands he gripped the top of the paper bag he'd brought with him.

I asked Noah and Casper to give us a minute. Obviously relieved, they hurried to join Graph Theory, who had just walked by in their uniforms.

"They're T-shirts," Marshall said. "Custom-printed T-shirts. You make everything here sound crazier than it is."

"I'm sorry," I said.

"Stop apologizing." He must have sensed that there was something missing from my apologies. He held out the paper bag. "I thought I'd bring you lunch."

"You're very sweet."

"Yes. I'm wonderful. Try to remember that."

On his way out, he introduced himself to Knot Theory. "Pleased to finally be meeting you," Marshall said, squeezing Clark's hand a little longer than he needed to. Clark didn't know what to say. It seemed like an effort for him to keep his mouth closed. His lips barely covered his teeth. I thought, *Of all people, why him?*

Marshall was thinking the same thing. "You're like my exact opposite," he said.

"I doubt we have much in common," Clark managed to say.

"There's at least one thing."

"Marshall!" I said.

"That was shitty. I apologize."

My face was burning up. "Please go."

"Right. I know. Can't mix work with Marshall."

"*Please*."

"Okay, okay, okay," he said. "I'm sorry. None of this is going the way I meant it to." He gave me a hug and followed it with a hopeful look. He kept his hands on my shoulders, forcing me to face him. "We'll talk at home?"

"Sure," I told him.

With Marshall gone, the twins and Charlie glared at me.

"What is wrong with you?" one of the twins asked.

"Who do you think you are?" the other added.

"You've hurt Clark," Charlie said.

"Keep your pet Neanderthal away from him."

Clark watched himself lay both his hands on the edge of the table. "I liked you," he said.

"I know. I read your emails. I'm sorry."

I had nothing else to say. I went down to my classroom, opened my lunch, and set the contents on my wooden table. Carton of milk, bag of cheese curls, an apple, and a ham and cheese sandwich on half a baguette. My father might have packed that lunch, save for the five-page

hand-written note I found at the bottom. It started with a detailed description of why Marshall wanted to marry me. That was followed by a tongue-in-cheek presentation—a bulleted list—of Marshall's many outstanding qualities. Then there was a discussion of the ways we made each other better-than-average people. I could see what he was up to: he was trying to prove that I should love him. The note ended with Marshall offering to forgive and forget, asking me to join him in putting all this behind us.

Kovács said he had good news. He paced up and down his office as he talked. It was time to take a break from flows, he said. "We have a saying in Hungary," he said. "Stretch only as far as your blanket can reach." But our work with flows had given him an idea. It had come to him in a dream—Metzger had nothing to do with it. One of our smaller arguments, he said, if expanded and extended, could yield a result for transformations. It wasn't on par with Knot Theory's paper, nothing to throw a parade over, but it was probably publishable. Kovács mapped it out for me, I tinkered, and by the end of the week, I had it. It started with Casper's lemma. "When life gives you lemons," I said to myself, in my windowless room, alone.

That night, after another delicious dinner that I couldn't appreciate, while Marshall was taking a shower, I called my father.

"Hwuh?" he said. It was nine o'clock in New Jersey—I'd

forgotten he'd be sleeping. His bedsprings whined as he righted himself. I pictured him in an old undershirt and boxer shorts. His arms were lean and strong from all the stretching and kneading, but the rest of his body was pale and soft. He was good to hug. I could hear him rubbing his whiskers.

"I'm sorry, Dad. I know how early you have to get up in the morning."

"Don't be sorry," he said. He coughed. I wished he'd quit smoking. "You okay?"

"I just needed to say hi." I lay back on the couch and stared at the ceiling, enjoying the depth of his voice.

"All right," he said. "That's wonderful." I could hear him up and walking around, sniffling. There was the rush of the spigot, the rising pitch of a glass being filled with water.

"I could call back tomorrow."

"Luce," he scolded. "I'm awake. What's up."

There was gulping, then the tap of the glass being set on the counter. I heard the refrigerator door and pictured its light whitening half the kitchen. There was never anything in the fridge but milk and eggs and sourdough starters. I heard the honk of a chair being pulled from the table. He sat and waited. He was always okay with not talking.

I asked him if he ever got lonely.

"Nah," he said. "I've got you."

"I'm a thousand miles away."

"I've got a telephone. I've got AOL."

"Your emails suck. They're never more than, like, two

sentences."

"I'm no good at writing."

"Is that why you never put notes in my lunchbox? I was the only kid I knew who never got one."

I heard him fidgeting, possibly shrugging. "I don't know," he said. "I never thought you were the kind of kid who needed notes in her lunchbox."

"What kind of kid was I?"

"Independent," he said, making it sound like a euphemism. "Pig-headed. And lazy."

"I'm not lazy."

"Thanks to me."

I laughed. "All that lawn-mowing and dish-washing? Is that your theory?"

"Sure."

"Then why didn't you teach me how to bake?"

Silence. The question had caught him off guard.

"You never seemed interested."

"I wasn't interested in mowing the lawn."

"No one's interested in mowing the lawn."

"My lack of interest in baking hurt your feelings."

"No," he said. "I didn't say that."

"But you would have liked to teach me, if I'd been interested. Because you love to bake. Am I right?"

"No. I love to pay the bills. I love to eat."

"Everyone loves to eat. You don't love to bake?"

"I like to get up in the morning," he said, getting defensive. "It's quiet. The light's nice. The birds sing different songs.

The streets are empty. No one else is awake. I like to be alone."

As he'd been speaking, I'd closed my eyes. The depth of his voice made it seem like it was coming from inside my own chest, like it was the sound of my own most secret feelings.

Marshall stepped into the doorway pinching his towel around his waist. I felt myself blushing. He looked hurt. My guilty expression must have made him think I was talking to Clark.

"Why am I being interrogated?" my father was saying.

Marshall made for the bedroom.

"Luce," my father said. "What's the matter. Let me talk to Marshall."

"Sorry, Dad," I said. "Sorry to bother you. I love you. Go back to bed."

"Luce," he said, as I hung up on him.

Marshall stood naked in the middle of our bedroom, his towel hanging from a knob on his dresser, a pair of underwear in his hand. He had a look on his face like he was considering sprinting out the door just like that.

"It was my father," I said.

"Then why were you blushing?"

"I don't know. I blush. You gave me a look."

"I see. It's my fault."

He stumbled and swore as he tried to step into the underwear.

"What are you doing? Sit down and talk to me."

"I can't fight with no clothes on!" He sat on the bed and leaned forward to rest his elbows on his knees. "I feel vulnerable."

I laid my hand on his smooth, shaved arm. "Don't cry. Let's not argue. There's no point."

He covered his face with his hands.

"This can't go on," I said.

"I know," he said. "We're getting married in six months. Could you please get over all this before then?"

The wedding. I couldn't remember the last time I'd thought about it.

"Leaving this place will help," he said, not waiting for me to respond. He removed his hands from his face and stared across the room, imagining his way back to better times. "I can't wait to return to our regular life."

Would our regular life still feel regular? I wasn't sure.

"How are you so calm?"

"Something's changed. I don't know. I feel different."

"I can see that." Now he looked desperately hopeful. "Let's make love."

I never liked when he said "make love."

"It's been weeks," he said.

"I'm aware. You think it'll help?"

He laughed. "Couldn't hurt."

"You're already undressed," I said. "Which is convenient."

"Yeah," he said, with a bitter smile. "This all has gone according to my plan."

The next day, I skipped work and slept in. Noah and Casper could finish things up on their own. Marshall woke me when he came back from his morning shift. He looked relieved to see me, as if he'd feared that after last night I might have cleared out with all my things. He rubbed my shoulder and tucked my hair behind my ear. He was fussy about scrubbing his hands, used a brush to get under the nails, but still they always smelled like deli sandwiches.

The sun glared through the window. A crystal prism that hung from a suction cup—an engagement present from Marshall's mother—cast the shards of a broken rainbow across the floor.

"Let's go somewhere," I said.

"Where do you want to go?"

I shrugged. "Away from here," I said. "What about that 'Manson Disturbance'? The cryptovolcanic thing you wanted to see."

"It's an impact structure. That's what the newer books call it."

"A crater," I said. "Even better."

Marshall drove. As we headed west out of town, we passed through the newest ring of development: repeated facades, gleaming vinyl siding, rows of baby trees propped up on stakes. A direct result, I thought, of the mistaken belief that the good life can be iterated. The wind smelled like hot soil. The sun flashed on the corn's long leaves. I turned to look at Marshall, and changing position let my hair out from where it was gathered and sent it whipping around my

face. Marshall frowned at the road, a good frown. It must have felt like we'd broken free of the summer's troubles and were finally escaping, starting fresh, seeking out a new way to be happy together.

An hour or so later, we climbed through some wooded hills, and afterwards the land got even flatter. The crops went on and on, to where the fields met the sky in a line. For hundreds of thousands of years, I thought, this was the straightest straightedge anyone ever saw. According to Marshall, this part of the country used to be underwater, the floor of a Cretaceous seaway—which at one point was partly vaporized by the thing we were driving to visit.

"This wasn't the one that killed the dinosaurs."

"No," Marshall said. "That's in the Yucatán."

"But there was mass devastation."

"Oh, yeah."

"Hey," I said. "Why don't you go to grad school for geology?"

He watched the road. "What are the odds we'd be near each other?"

I let it go. We got off the interstate. The corn was like a green wall running along the road, interrupted every few minutes by a creek, a windbreak, a cluster of steel sheds and farm buildings. We passed through a town with a row of old brick factories lined up along a river. Marshall had brought a copy of the WPA guide to Iowa, which said that we were near one of the world's largest gypsum deposits. The factories were gypsum mills. I pictured miners

tracking white powder, like flour, into their living rooms. On the town's outskirts we passed a tractor dealer selling equipment that might have been built for the moon—giant plows, toothed buckets, caterpillar treads that could flatten a car without noticing. Then we passed a wooden fort surrounded by a wall of vertical logs. The guidebook said that in the nineteenth century the area had been terrorized by a Sioux Indian named Two Fingers. The name went unexplained.

It felt odd, after these months spent stooped over desks, finally to be seeing the place where I'd been living. "I'm glad you're getting a chance to do this," I said.

"I'm glad *we're* doing it."

"That's what I meant," I said. "The last few weeks have been hard."

Marshall seemed mistrustful of my tone. "Look at it this way," he said. "You got a result. You'll go home with a publication credit. You made some good friends." Saying "good friends" caused him to wince. "That's what you wanted, right? You should be happy."

"You need to stop telling me I should be happy."

"I'm just trying to cheer you up."

"Maybe I don't want to be cheered up."

"Well," he sighed. "Then I guess I'll just have to be patient."

"Marshall—"

"Look. We're here."

The streets of Manson formed an orderly grid that

ended abruptly at the edge of the fields. There was a single stoplight. There was nothing in the old guidebook about nondescript Manson or its impact structure. We pulled into a gas station at the end of town. As Marshall pumped gas, he kept glancing over his shoulder at me.

"Lucy," he said, as he very gently placed the nozzle back on the pump. "So you aren't perfect. It isn't the end of the world."

I didn't answer. I went into the station's store for a soda, and Marshall followed. The sun shone dimly through high, dusty windows. The cashier, a man close to my father's age, sat in a cushioned office chair behind the counter. He was reading a folded newspaper.

"Excuse me," I said.

The man set his paper on his knee.

"We're looking for the Impact Structure."

The man laughed and said, "Young lady, you're standing on it."

The hairs on my arms stood on end.

"It's buried underground," Marshall explained. "It's like twenty-five miles across. This is all there is to see." He sounded apologetic. He thought I was disappointed, that I was wondering why we'd driven all the way out there, when actually I was thrilled, overwhelmed by a sudden sense of awesome possibility.

"It's also an aquifer," Marshall added. "I hear they have great water."

The cashier smiled at us—a hopeful young couple out

exploring on a hot summer day. "Know what?" he said. "Hold on a second." The man groaned as he got up from his chair, then disappeared through a door behind the counter.

Marshall put his hand on my back. I shrugged him off. It was time. I was about to break our history over my knee.

"Listen," I said.

The man returned and handed Marshall a glass of water. "On the house," he said.

Marshall took a drink and smiled at me. He handed me the glass and waited for whatever it was I had to say. I looked out the window at that great green dead ocean and drank. The water tasted great.

The sky darkened and lowered its foot. The floor heaved, the shelving rattled. Marshall looked afraid. He saw then what he'd been trying so hard to avoid seeing: that I wanted the world to end. That I needed boiling oceans, burning skies, mass extinctions. That I couldn't settle for a simple, quiet failure. Saying that to myself made everything different. It felt as if the world had been struck, and changed, and moved, but it was only me, becoming.

Earle McCartney was awarded the San Francisco Foundation's Joseph Henry Jackson Award in 2013. His fiction has appeared or is forthcoming in *ZYZZYVA*, *The Common*, *Meridian*, *The Greensboro Review*, *Beloit Fiction Journal*, and elsewhere. He lives with his wife and daughters in San Francisco.