Writing an Engineering Paper

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What We’ll Cover

- Writing theory
- Structure
- Readability
- Common grammatical problems

Some Writing Theory…

The Importance of Writing

If you don’t write about/publish your work, it is as if you never did it!

(If a tree falls in a forest and no one is there to hear it, does it make a sound?)

The Importance of *Good* Writing

- You want your writing get published
- You want your writing to be read
- You want your writing to be understood
  - For the good of your field
  - For the good of your reputation
  - For the good of your career (impressive papers help you get jobs!)

Entering the Conversation

- Think of all the work that has been done in your field as a "conversation"
- Each researcher/writer has contributed something (an "**argument**") to this dialogue
- What you write (your **argument**) is in some way a response to what someone else has said
  - you disagree, you're agreeing but adding new evidence, etc.
- **Academic writing = persuasive writing!**

Adapted from *They Say, I Say* by Graff & Birkenstein

“They say _____; I say _____.”

- Present your ideas as a response to some other person or group
- If your own argument doesn't identify the "they say" that you're responding to, then it probably won't make sense
- (It is what others are saying and thinking that motivates our writing and gives it a reason for being)

Adapted from *They Say, I Say* by Graff & Birkenstein

Activity

- Think about a paper you’re writing now (or a project you’re working on)

- Write down **your argument**
  - “They say ….”
  - “I say….”

Structure

Science Paper Structure

(follows classical scientific method)

- Question
- **Hypothesis**
- Methods: Experiment to test hypothesis
- Results of experiment
- Conclusion: accept or reject hypothesis

Engineering Paper Structure

(subtly different)

- Question → Problem
- **Hypothesis → Proposed solution**
- Experiment → Evaluation of proposed solution
- Results → Analysis
- Conclusion → Conclusion

Adapted from “How to Read an Engineering Paper” by W. G. Griswold

Introduction/Background

- **Contextualize**
  - What is the big picture?
  - What problem are you trying to solve?
  - Why is it important?
  - What work has been done by others in the past that leads up to your work? (literature review)
  - How does your work fit within the context of the broader conversation?
  - How is your work the natural next step?
  - “They say _____; I say _____.”
- Consider your **audience**
- Explicitly state your **argument**

Methods

- Describe your methods/experiments/procedures/test benches/etc. to the level of detail such that a reader can replicate your results
- Avoid vague statements like “We used graph theory followed by convex optimization.” (How? To do what? Why?)

Discussion/Conclusion

- Contextualize again
  - How do these results relate back to the big picture?
  - What are the contributions of this work? Why is it important?
  - What are the future directions of this research?
  - What questions are you left with?
  - What is the **takeaway message** from this paper?

Abstract

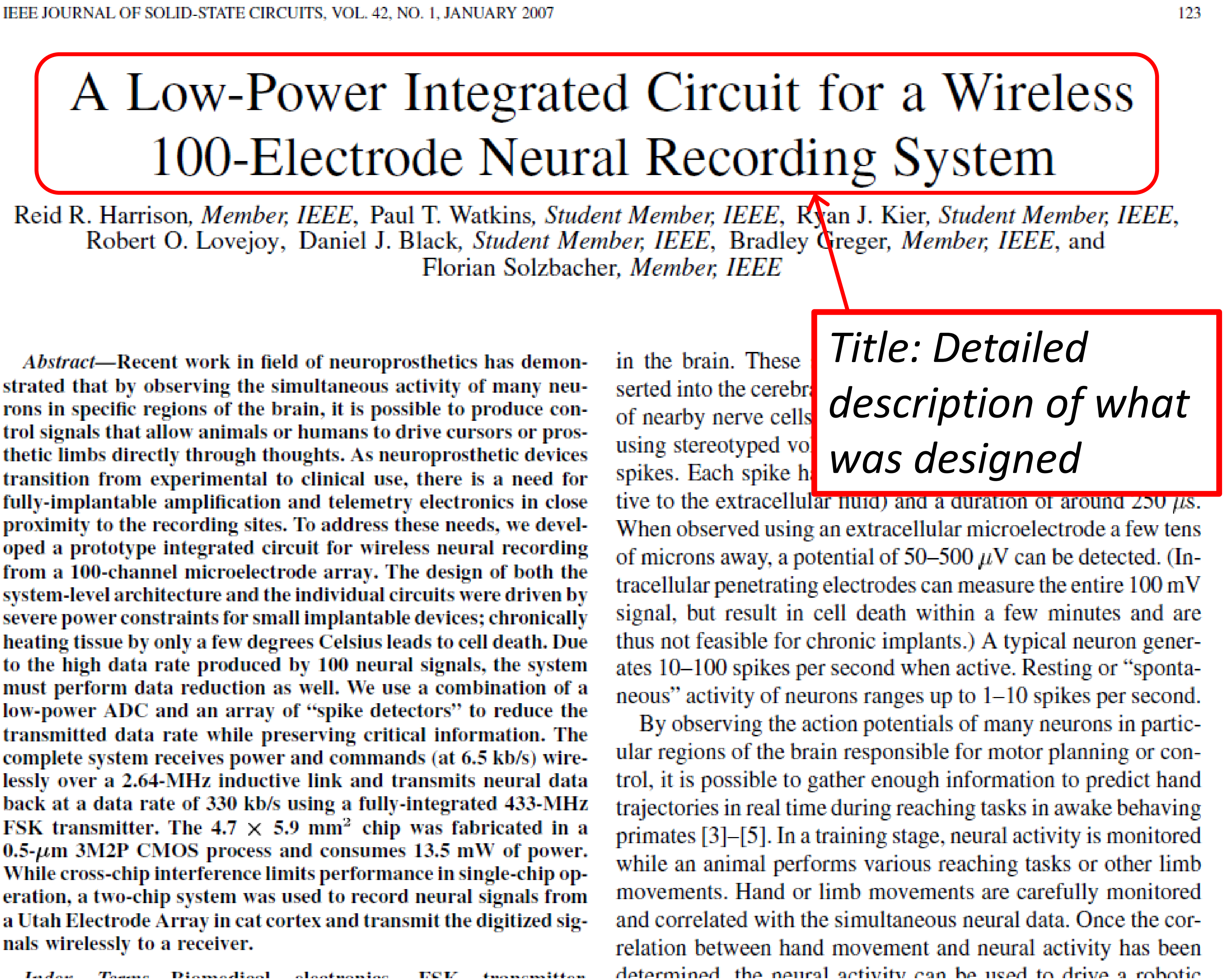
- Should include
  - Statement that places your work in context
  - Brief description of methods
  - Main results
  - Main conclusions
- Aim for informative, not descriptive
  - “Conclusions as to the effectiveness of this method of carbon monoxide monitoring are given, together with suggested recommendations for future air quality sampling programmes.”

vs.

  - “We concluded that the methods were effective in measuring the spatial distribution of carbon monoxide, estimating commuter exposure, and assessing the effectiveness of fixed-site monitors. An on-road monitoring programme is recommended as a supplement to the present system of monitoring air quality.”

Adapted from “Writing for Science and Engineering” by H. Silyn-Roberts

Example



A Low-Power Integrated Circuit for a Wireless 100-Electrode Neural Recording System

Reid R. Harrison, *Member, IEEE*, Paul T. Watkins, *Student Member, IEEE*, Ryan J. Kier, *Student Member, IEEE*,
Robert O. Lovejoy, Daniel J. Black, *Student Member, IEEE*, Bradley Greger, *Member, IEEE*, and
Florian Solzbacher, *Member, IEEE*

Abstract—Recent work in field of neuroprosthetics has demonstrated that by observing the simultaneous activity of many neurons in specific regions of the brain, it is possible to produce control signals that allow animals or humans to drive cursors or prosthetic limbs directly through thoughts. As neuroprosthetic devices transition from experimental to clinical use, there is a need for fully-implantable amplification and telemetry electronics in close proximity to the recording sites. To address these needs, we developed a prototype integrated circuit for wireless neural recording from a 100-channel microelectrode array. The design of both the system-level architecture and the individual circuits were driven by severe power constraints for small implantable devices; chronically heating tissue by only a few degrees Celsius leads to cell death. Due to the high data rate produced by 100 neural signals, the system must perform data reduction as well. We use a combination of a low-power ADC and an array of "spike detectors" to reduce the transmitted data rate while preserving critical information. The complete system receives power and commands (at 6.5 kb/s) wirelessly over a 2.64-MHz inductive link and transmits neural data back at a data rate of 330 kb/s using a fully-integrated 433-MHz FSK transmitter. The 4.7 × 5.9 mm^2 chip was fabricated in a 0.5-μm 3M2P CMOS process and consumes 13.5 mW of power. While cross-chip interference limits performance in single-chip operation, a two-chip system was used to record neural signals from a Utah Electrode Array in cat cortex and transmit the digitized signals wirelessly to a receiver.

***Index Terms*—Biomedical electronics, FSK transmitter,**

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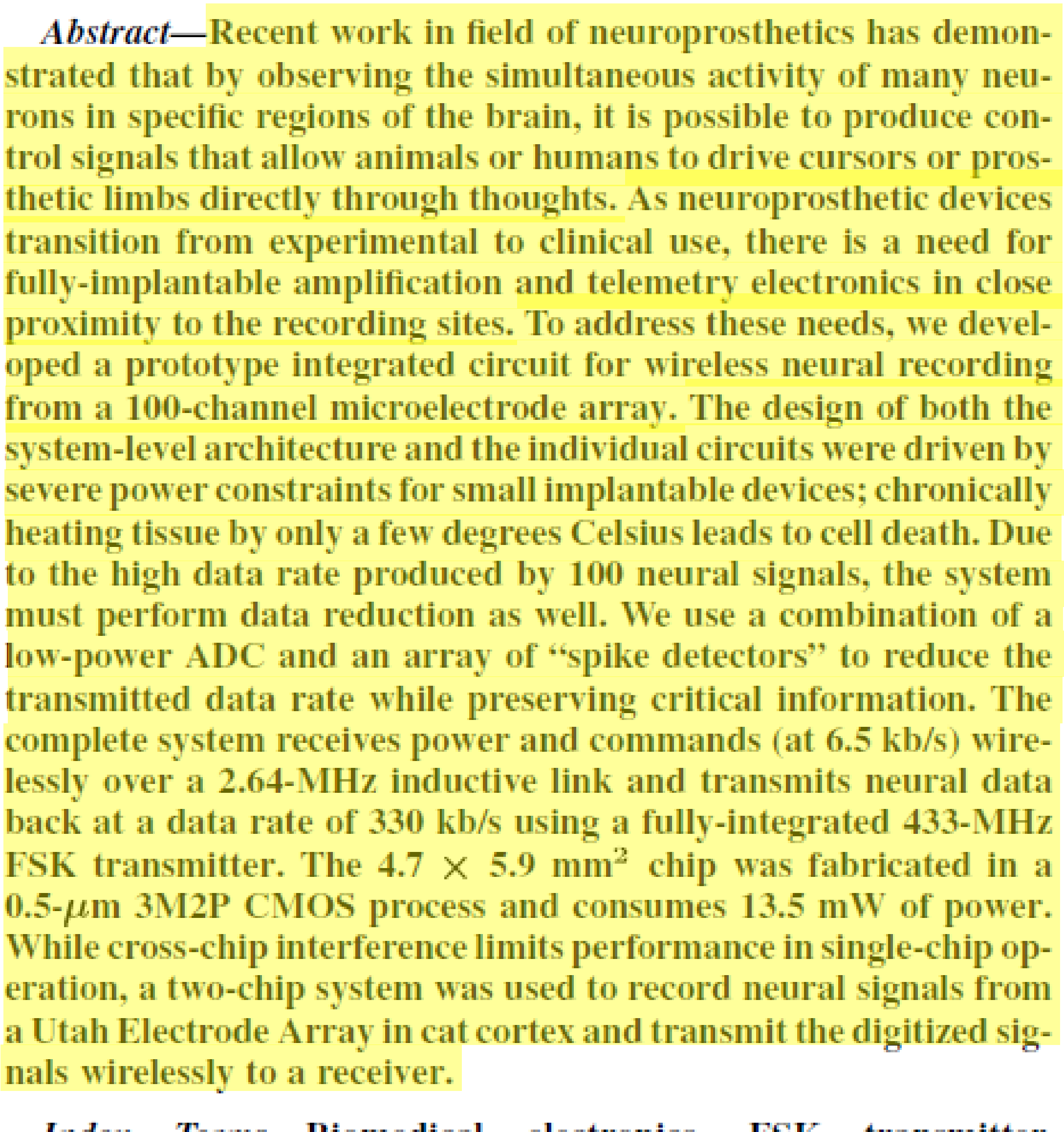
By observing the action potentials of many neurons in particular regions of the brain responsible for motor planning or control, it is possible to gather enough information to predict hand trajectories in real time during reaching tasks in awake behaving primates [3]–[5]. In a training stage, neural activity is monitored while an animal performs various reaching tasks or other limb movements. Hand or limb movements are carefully monitored and correlated with the simultaneous neural data. Once the correlation between hand movement and neural activity has been determined, the neural activity can be used to drive a robotic

Title: Detailed description of what was designed



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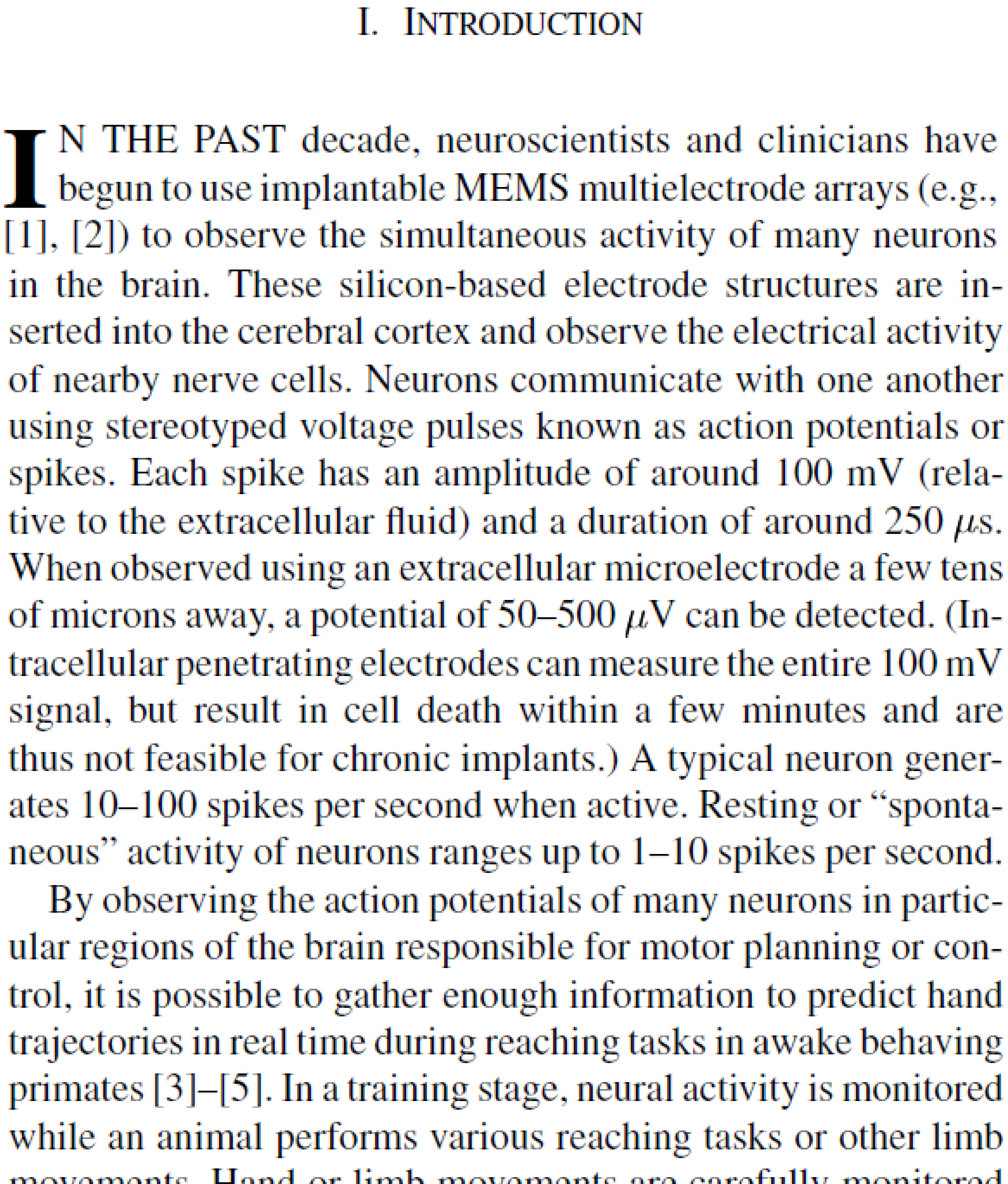
Setting the stage

Identifying a need

Proposed solution

Design constraints

Brief results

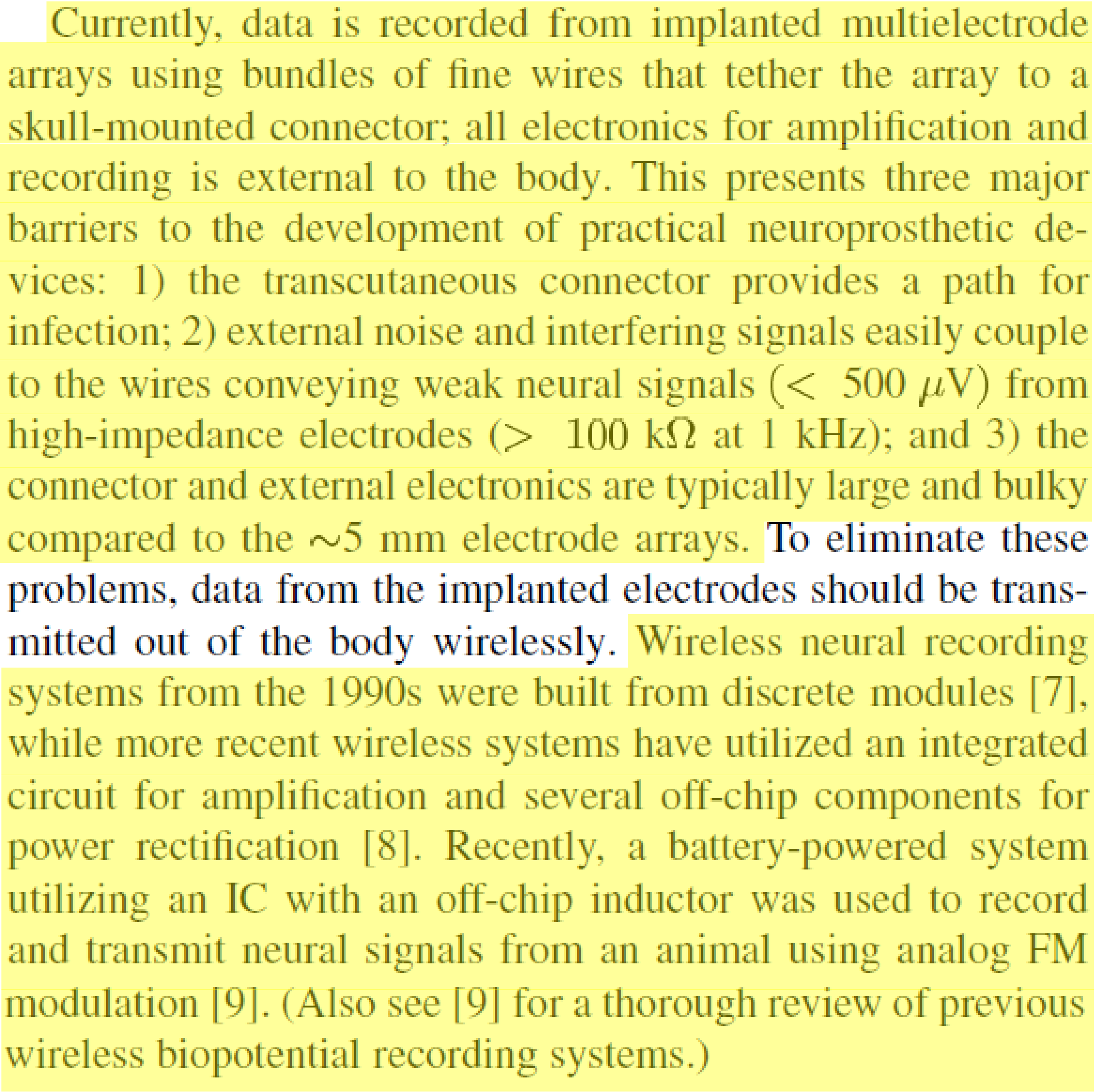


I. INTRODUCTION

IN THE PAST decade, neuroscientists and clinicians have begun to use implantable MEMS multielectrode arrays (e.g., [1], [2]) to observe the simultaneous activity of many neurons in the brain. These silicon-based electrode structures are inserted into the cerebral cortex and observe the electrical activity of nearby nerve cells. Neurons communicate with one another using stereotyped voltage pulses known as action potentials or spikes. Each spike has an amplitude of around 100 mV (relative to the extracellular fluid) and a duration of around 250 μs. When observed using an extracellular microelectrode a few tens of microns away, a potential of 50–500 μV can be detected. (Intracellular penetrating electrodes can measure the entire 100 mV signal, but result in cell death within a few minutes and are thus not feasible for chronic implants.) A typical neuron generates 10–100 spikes per second when active. Resting or "spontaneous" activity of neurons ranges up to 1–10 spikes per second.

By observing the action potentials of many neurons in particular regions of the brain responsible for motor planning or control, it is possible to gather enough information to predict hand trajectories in real time during reaching tasks in awake behaving primates [3]–[5]. In a training stage, neural activity is monitored while an animal performs various reaching tasks or other limb movements. Hand or limb movements are carefully monitored

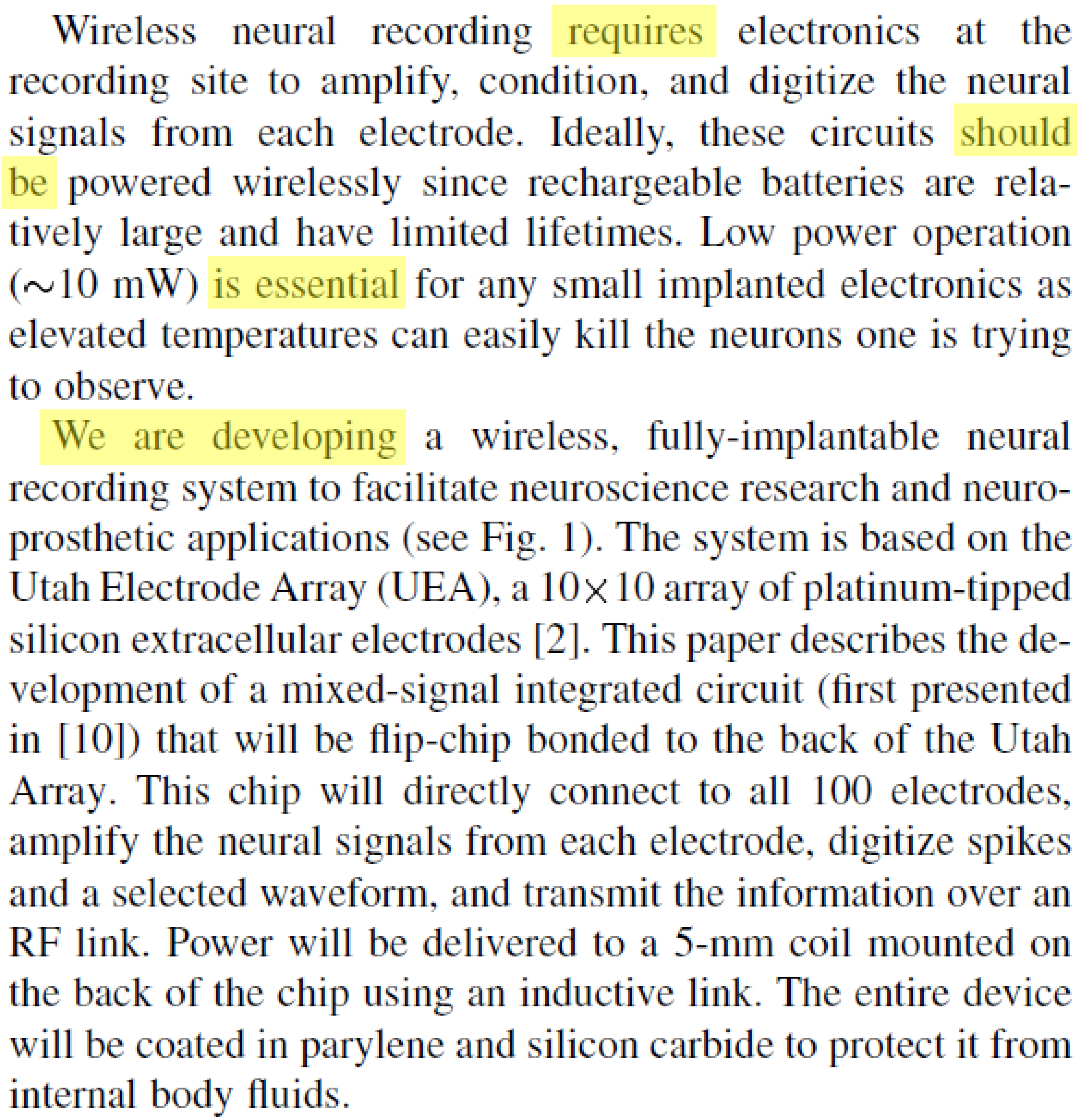
Background
(2 paragraphs)



Currently, data is recorded from implanted multielectrode arrays using bundles of fine wires that tether the array to a skull-mounted connector; all electronics for amplification and recording is external to the body. This presents three major barriers to the development of practical neuroprosthetic devices: 1) the transcutaneous connector provides a path for infection; 2) external noise and interfering signals easily couple to the wires conveying weak neural signals ($< 500\ \mu$V) from high-impedance electrodes (> 100 kΩ at 1 kHz); and 3) the connector and external electronics are typically large and bulky compared to the $\sim$5 mm electrode arrays. To eliminate these problems, data from the implanted electrodes should be transmitted out of the body wirelessly. Wireless neural recording systems from the 1990s were built from discrete modules [7], while more recent wireless systems have utilized an integrated circuit for amplification and several off-chip components for power rectification [8]. Recently, a battery-powered system utilizing an IC with an off-chip inductor was used to record and transmit neural signals from an animal using analog FM modulation [9]. (Also see [9] for a thorough review of previous wireless biopotential recording systems.)

Problems with current state of the art

Literature review: How others have attempted to address these problems



Wireless neural recording requires electronics at the recording site to amplify, condition, and digitize the neural signals from each electrode. Ideally, these circuits should be powered wirelessly since rechargeable batteries are relatively large and have limited lifetimes. Low power operation (∼10 mW) is essential for any small implanted electronics as elevated temperatures can easily kill the neurons one is trying to observe.

We are developing a wireless, fully-implantable neural recording system to facilitate neuroscience research and neuroprosthetic applications (see Fig. 1). The system is based on the Utah Electrode Array (UEA), a 10×10 array of platinum-tipped silicon extracellular electrodes [2]. This paper describes the development of a mixed-signal integrated circuit (first presented in [10]) that will be flip-chip bonded to the back of the Utah Array. This chip will directly connect to all 100 electrodes, amplify the neural signals from each electrode, digitize spikes and a selected waveform, and transmit the information over an RF link. Power will be delivered to a 5-mm coil mounted on the back of the chip using an inductive link. The entire device will be coated in parylene and silicon carbide to protect it from internal body fluids.

Design constraints

Proposed solution

Body

Top-level system description

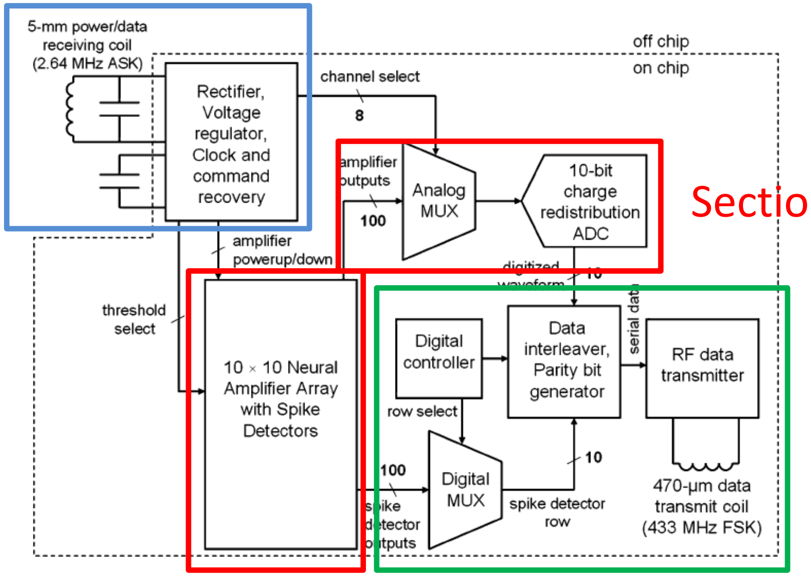
→ II. System Design

Detailed descriptions of individual components of system (contains some results)

III. Wireless…Transmission

IV. Spike Recording and Detection

V. FSK Data Transmission

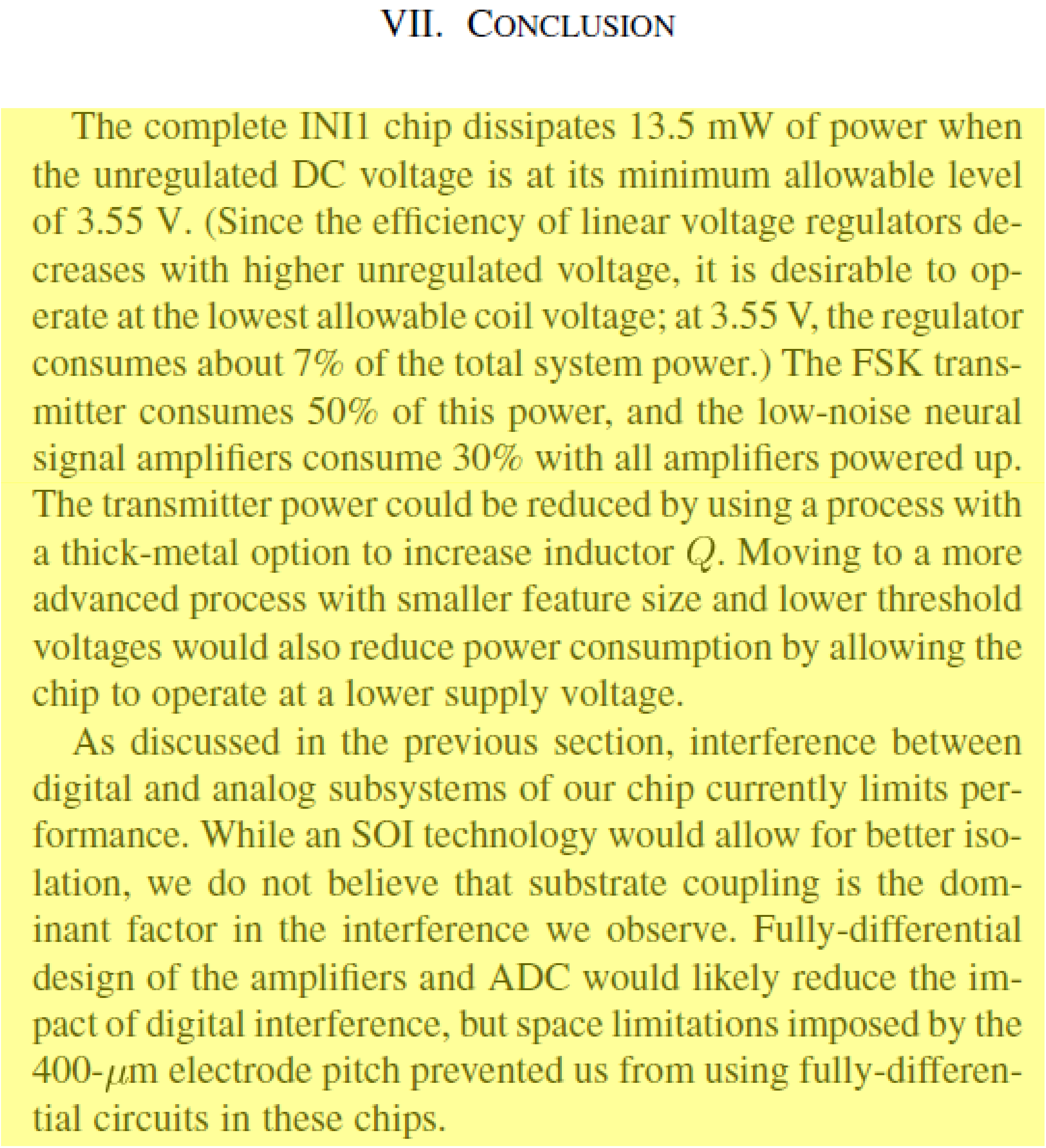


Section III

Section IV

Section V

VI. Wireless Recording from Cortex



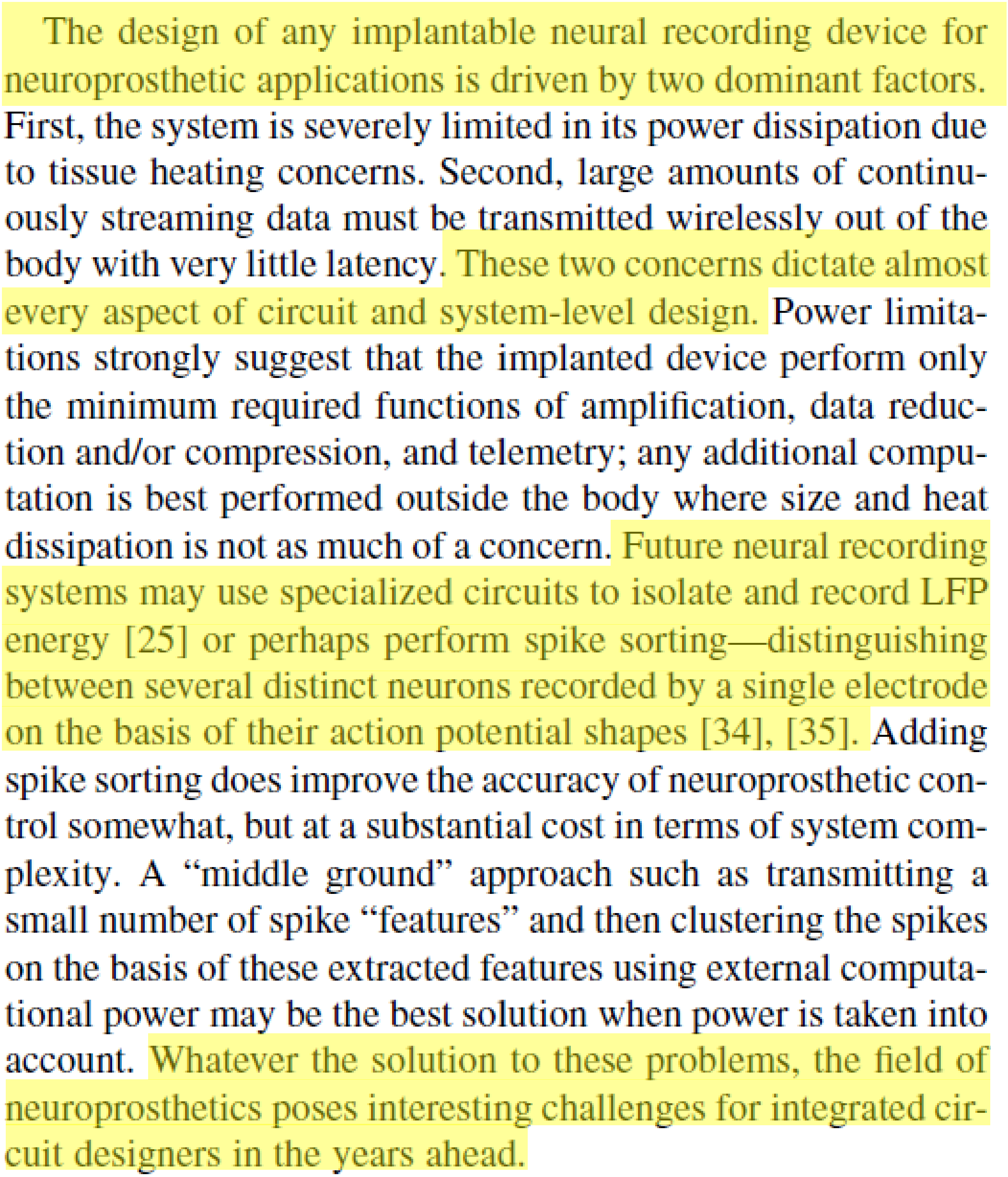
VII. CONCLUSION

The complete INI1 chip dissipates 13.5 mW of power when the unregulated DC voltage is at its minimum allowable level of 3.55 V. (Since the efficiency of linear voltage regulators decreases with higher unregulated voltage, it is desirable to operate at the lowest allowable coil voltage; at 3.55 V, the regulator consumes about 7% of the total system power.) The FSK transmitter consumes 50% of this power, and the low-noise neural signal amplifiers consume 30% with all amplifiers powered up. The transmitter power could be reduced by using a process with a thick-metal option to increase inductor Q. Moving to a more advanced process with smaller feature size and lower threshold voltages would also reduce power consumption by allowing the chip to operate at a lower supply voltage.

As discussed in the previous section, interference between digital and analog subsystems of our chip currently limits performance. While an SOI technology would allow for better isolation, we do not believe that substrate coupling is the dominant factor in the interference we observe. Fully-differential design of the amplifiers and ADC would likely reduce the impact of digital interference, but space limitations imposed by the 400-μm electrode pitch prevented us from using fully-differential circuits in these chips.

Summarizes results

Acknowledges limitations of their approach and possible ways these limitations could be addressed



The design of any implantable neural recording device for neuroprosthetic applications is driven by two dominant factors. First, the system is severely limited in its power dissipation due to tissue heating concerns. Second, large amounts of continuously streaming data must be transmitted wirelessly out of the body with very little latency. These two concerns dictate almost every aspect of circuit and system-level design. Power limitations strongly suggest that the implanted device perform only the minimum required functions of amplification, data reduction and/or compression, and telemetry; any additional computation is best performed outside the body where size and heat dissipation is not as much of a concern. Future neural recording systems may use specialized circuits to isolate and record LFP energy [25] or perhaps perform spike sorting—distinguishing between several distinct neurons recorded by a single electrode on the basis of their action potential shapes [34], [35]. Adding spike sorting does improve the accuracy of neuroprosthetic control somewhat, but at a substantial cost in terms of system complexity. A "middle ground" approach such as transmitting a small number of spike "features" and then clustering the spikes on the basis of these extracted features using external computational power may be the best solution when power is taken into account. Whatever the solution to these problems, the field of neuroprosthetics poses interesting challenges for integrated circuit designers in the years ahead.

Taking a step back; Looking to the future

Readability

“People won’t read what they *can’t* read.”

Adapted from “Readability Counts” by D. Burman et al.

Readability…

- shortens review time,
- improves the odds of acceptance,
- increases the readership,
- enhances the author’s reputation.

Adapted from “Readability Counts” by D. Burman et al.

Tips for Improving Readability

- **Tell a story**!
- Be **concise** and **efficient**
  - use the minimum number of words necessary to make your point
- Say things in the **simplest** way possible
  - don’t use big words, excessive technical jargon, or long, complicated sentences *just to sound smart*
- Eliminate jargon
  - try to explain things such that a non-expert can understand

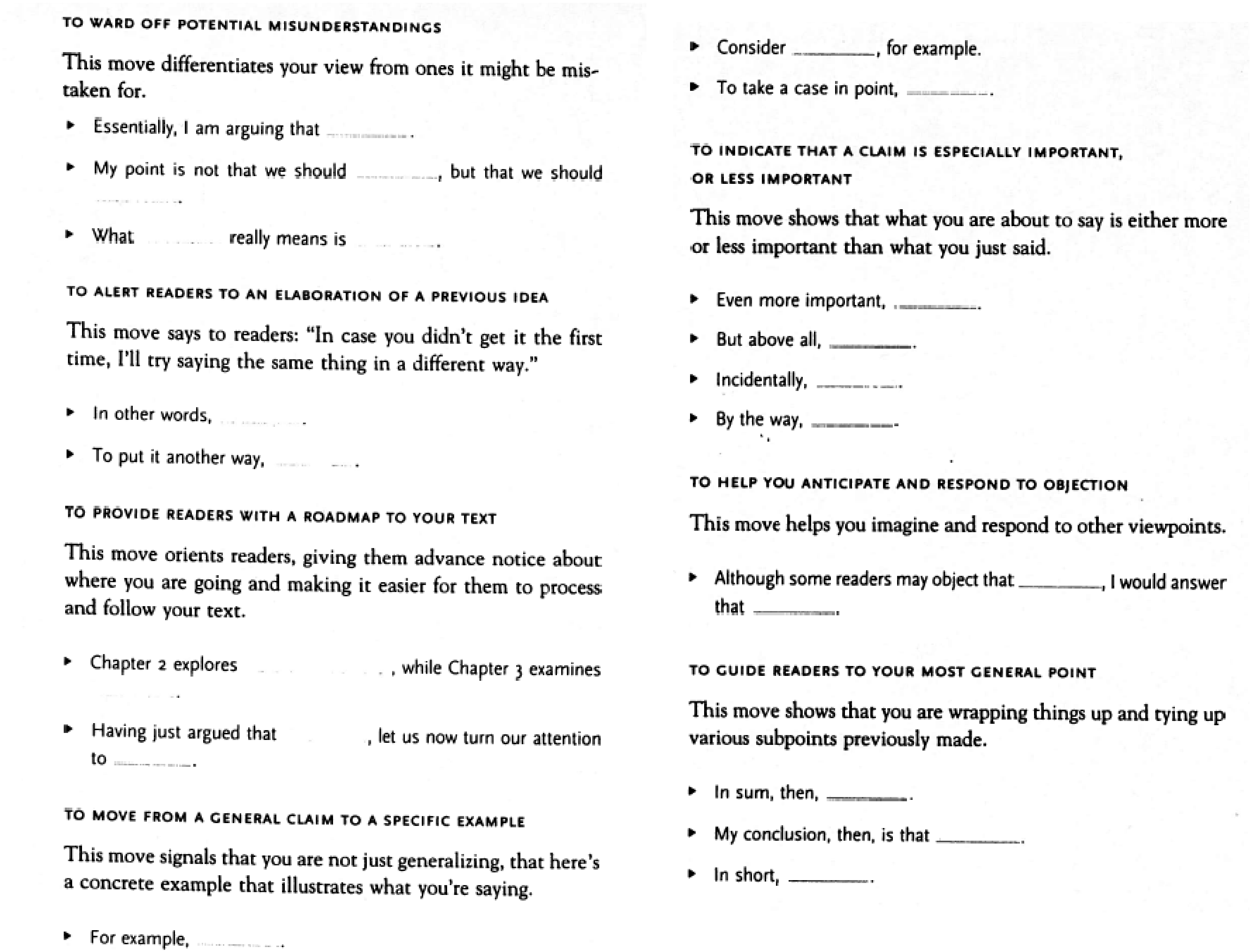
More Tips for Improving Readability

- Use “metacommentary” (“metadiscourse”)
- Use transitions

Metacommentary

- “beyond/transcending commentary”
- Telling an audience how to interpret what you have already said or are about to say. Are you…
  - Elaborating on a previous idea?
  - Moving from general to specific?
  - Indicating the relative importance of a claim?
  - Finally arriving at your main point?
- Provides the reader with “guide posts” for navigating through the writing

Adapted from *They Say, I Say* by Graff & Birkenstein



TO WARD OFF POTENTIAL MISUNDERSTANDINGS

This move differentiates your view from ones it might be mistaken for.

- Essentially, I am arguing that ____.
- My point is not that we should ____, but that we should ____.
- What ____ really means is ____.

TO ALERT READERS TO AN ELABORATION OF A PREVIOUS IDEA

This move says to readers: "In case you didn't get it the first time, I'll try saying the same thing in a different way."

- In other words, ____.
- To put it another way, ____.

TO PROVIDE READERS WITH A ROADMAP TO YOUR TEXT

This move orients readers, giving them advance notice about where you are going and making it easier for them to process and follow your text.

- Chapter 2 explores ____, while Chapter 3 examines ____.
- Having just argued that ____, let us now turn our attention to ____.

TO MOVE FROM A GENERAL CLAIM TO A SPECIFIC EXAMPLE

This move signals that you are not just generalizing, that here's a concrete example that illustrates what you're saying.

- For example, ____.
- ____, for instance, demonstrates ____.
- Consider ____, for example.
- To take a case in point, ____.

TO INDICATE THAT A CLAIM IS ESPECIALLY IMPORTANT, OR LESS IMPORTANT

This move shows that what you are about to say is either more or less important than what you just said.

- Even more important, ____.
- But above all, ____.
- Incidentally, ____.
- By the way, ____.

TO HELP YOU ANTICIPATE AND RESPOND TO OBJECTION

This move helps you imagine and respond to other viewpoints.

- Although some readers may object that ____, I would answer that ____.

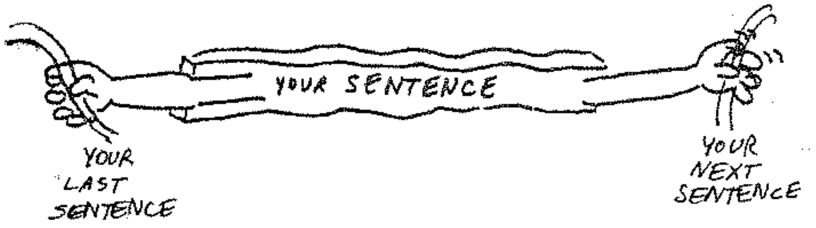
TO GUIDE READERS TO YOUR MOST GENERAL POINT

This move shows that you are wrapping things up and tying up various subpoints previously made.

- In sum, then, ____.
- My conclusion, then, is that ____.
- In short, ____.

They Say, I Say by Graff & Birkenstein

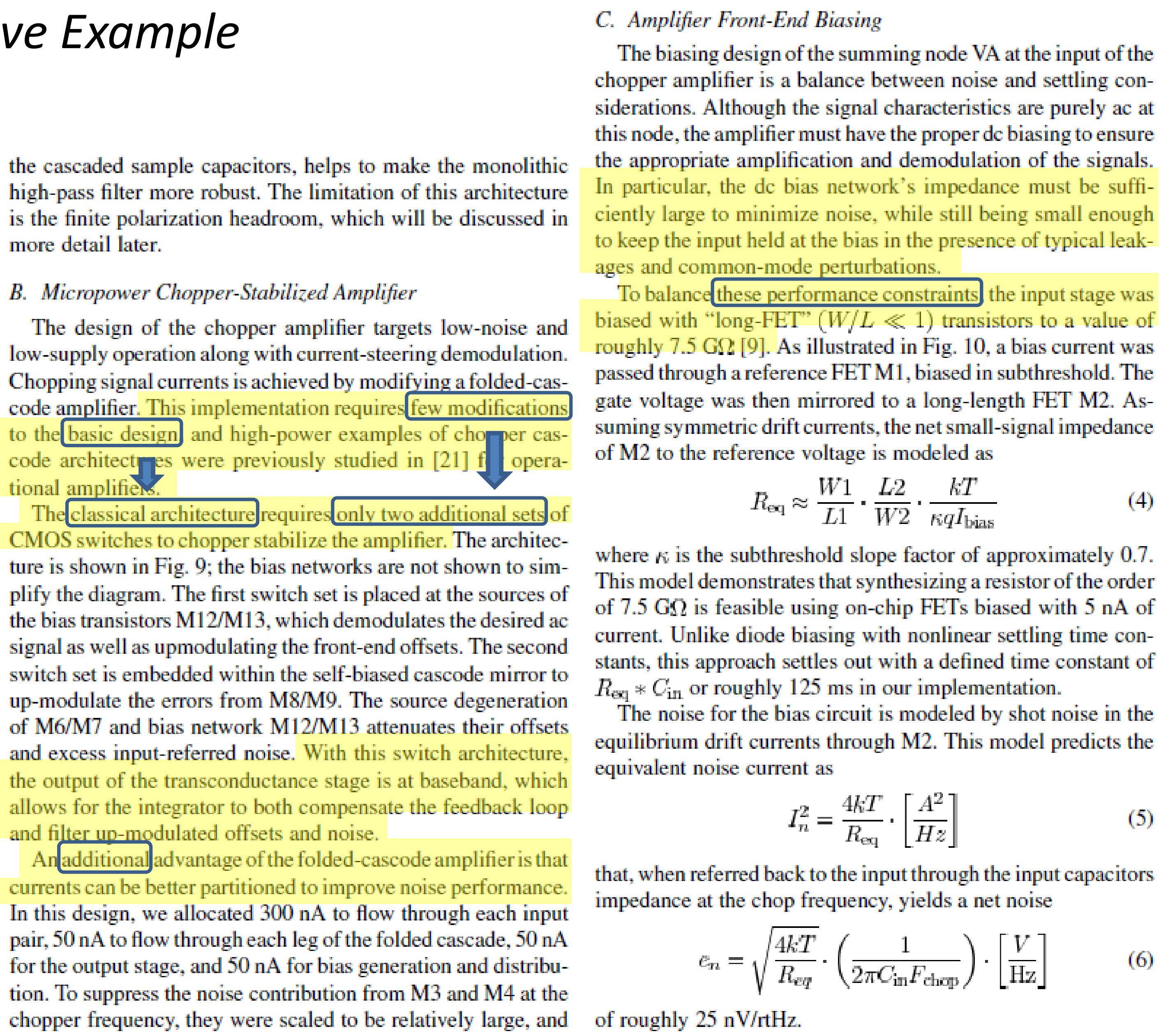
Techniques for Good Transitions (from *They Say/I Say*)



- **Use transition words**
- **Use pointing words**
  - Point/refer back to a concept in the previous sentence
- **Repeat key terms and phrases**
  - Develop a constellation of key terms and phrases, including their synonyms and antonyms, that you repeat throughout your text

Adapted from *They Say, I Say* by Graff & Birkenstein

Positive Example



the cascaded sample capacitors, helps to make the monolithic high-pass filter more robust. The limitation of this architecture is the finite polarization headroom, which will be discussed in more detail later.

B. Micropower Chopper-Stabilized Amplifier

The design of the chopper amplifier targets low-noise and low-supply operation along with current-steering demodulation. Chopping signal currents is achieved by modifying a folded-cascode amplifier. This implementation requires few modifications to the basic design and high-power examples of chopper cascode architectures were previously studied in [21] for operational amplifiers.

The classical architecture requires only two additional sets of CMOS switches to chopper stabilize the amplifier. The architecture is shown in Fig. 9; the bias networks are not shown to simplify the diagram. The first switch set is placed at the sources of the bias transistors M12/M13, which demodulates the desired ac signal as well as upmodulating the front-end offsets. The second switch set is embedded within the self-biased cascode mirror to up-modulate the errors from M8/M9. The source degeneration of M6/M7 and bias network M12/M13 attenuates their offsets and excess input-referred noise. With this switch architecture, the output of the transconductance stage is at baseband, which allows for the integrator to both compensate the feedback loop and filter up-modulated offsets and noise.

An additional advantage of the folded-cascode amplifier is that currents can be better partitioned to improve noise performance. In this design, we allocated 300 nA to flow through each input pair, 50 nA to flow through each leg of the folded cascade, 50 nA for the output stage, and 50 nA for bias generation and distribution. To suppress the noise contribution from M3 and M4 at the chopper frequency, they were scaled to be relatively large, and

C. Amplifier Front-End Biasing

The biasing design of the summing node VA at the input of the chopper amplifier is a balance between noise and settling considerations. Although the signal characteristics are purely ac at this node, the amplifier must have the proper dc biasing to ensure the appropriate amplification and demodulation of the signals. In particular, the dc bias network's impedance must be sufficiently large to minimize noise, while still being small enough to keep the input held at the bias in the presence of typical leakages and common-mode perturbations.

To balance these performance constraints the input stage was biased with "long-FET" ($W/L \ll 1$) transistors to a value of roughly 7.5 GΩ [9]. As illustrated in Fig. 10, a bias current was passed through a reference FET M1, biased in subthreshold. The gate voltage was then mirrored to a long-length FET M2. Assuming symmetric drift currents, the net small-signal impedance of M2 to the reference voltage is modeled as

$$R_{\rm eq} \approx \frac{W1}{L1}\cdot\frac{L2}{W2}\cdot\frac{kT}{\kappa q I_{\rm bias}} \qquad (4)$$

where κ is the subthreshold slope factor of approximately 0.7. This model demonstrates that synthesizing a resistor of the order of 7.5 GΩ is feasible using on-chip FETs biased with 5 nA of current. Unlike diode biasing with nonlinear settling time constants, this approach settles out with a defined time constant of $R_{\rm eq} * C_{\rm in}$ or roughly 125 ms in our implementation.

The noise for the bias circuit is modeled by shot noise in the equilibrium drift currents through M2. This model predicts the equivalent noise current as

$$I_n^2 = \frac{4kT}{R_{\rm eq}}\cdot\left[\frac{A^2}{Hz}\right] \qquad (5)$$

that, when referred back to the input through the input capacitors impedance at the chop frequency, yields a net noise

$$e_n = \sqrt{\frac{4kT}{R_{eq}}}\cdot\left(\frac{1}{2\pi C_{\rm in}F_{\rm chop}}\right)\cdot\left[\frac{V}{\rm Hz}\right] \qquad (6)$$

of roughly 25 nV/rtHz.

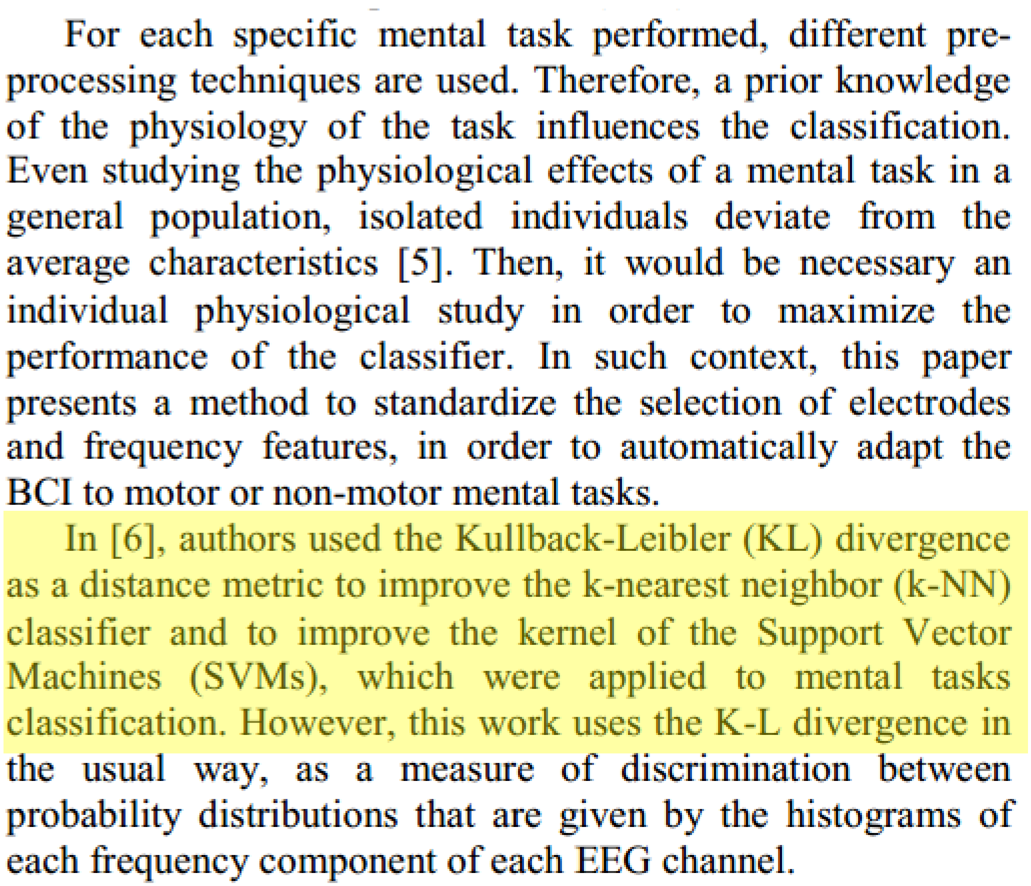
Repeating Key Terms

Transition Words

Pointing Words

Denison et al., JSSC 2007

Negative Example – No transitions between paragraphs

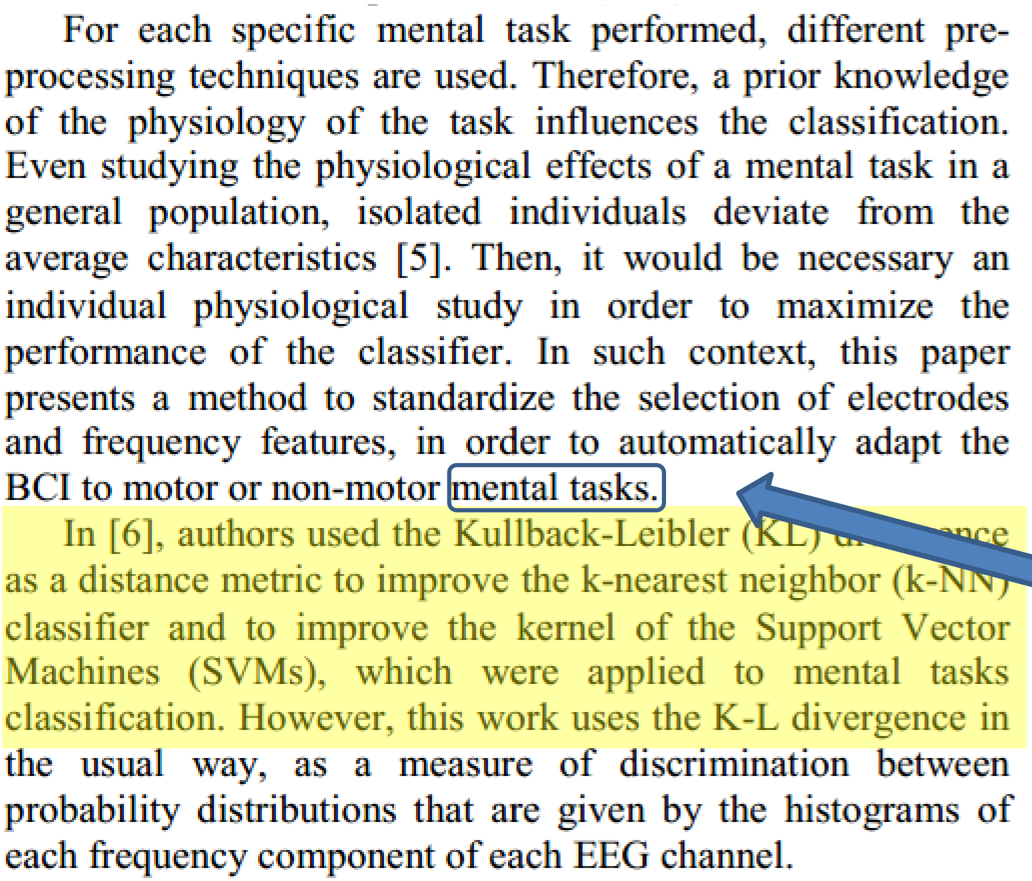


For each specific mental task performed, different pre-processing techniques are used. Therefore, a prior knowledge of the physiology of the task influences the classification. Even studying the physiological effects of a mental task in a general population, isolated individuals deviate from the average characteristics [5]. Then, it would be necessary an individual physiological study in order to maximize the performance of the classifier. In such context, this paper presents a method to standardize the selection of electrodes and frequency features, in order to automatically adapt the BCI to motor or non-motor mental tasks.

In [6], authors used the Kullback-Leibler (KL) divergence as a distance metric to improve the k-nearest neighbor (k-NN) classifier and to improve the kernel of the Support Vector Machines (SVMs), which were applied to mental tasks classification. However, this work uses the K-L divergence in the usual way, as a measure of discrimination between probability distributions that are given by the histograms of each frequency component of each EEG channel.

Benevides et al., ISCAS 2011

Negative Example – Improved



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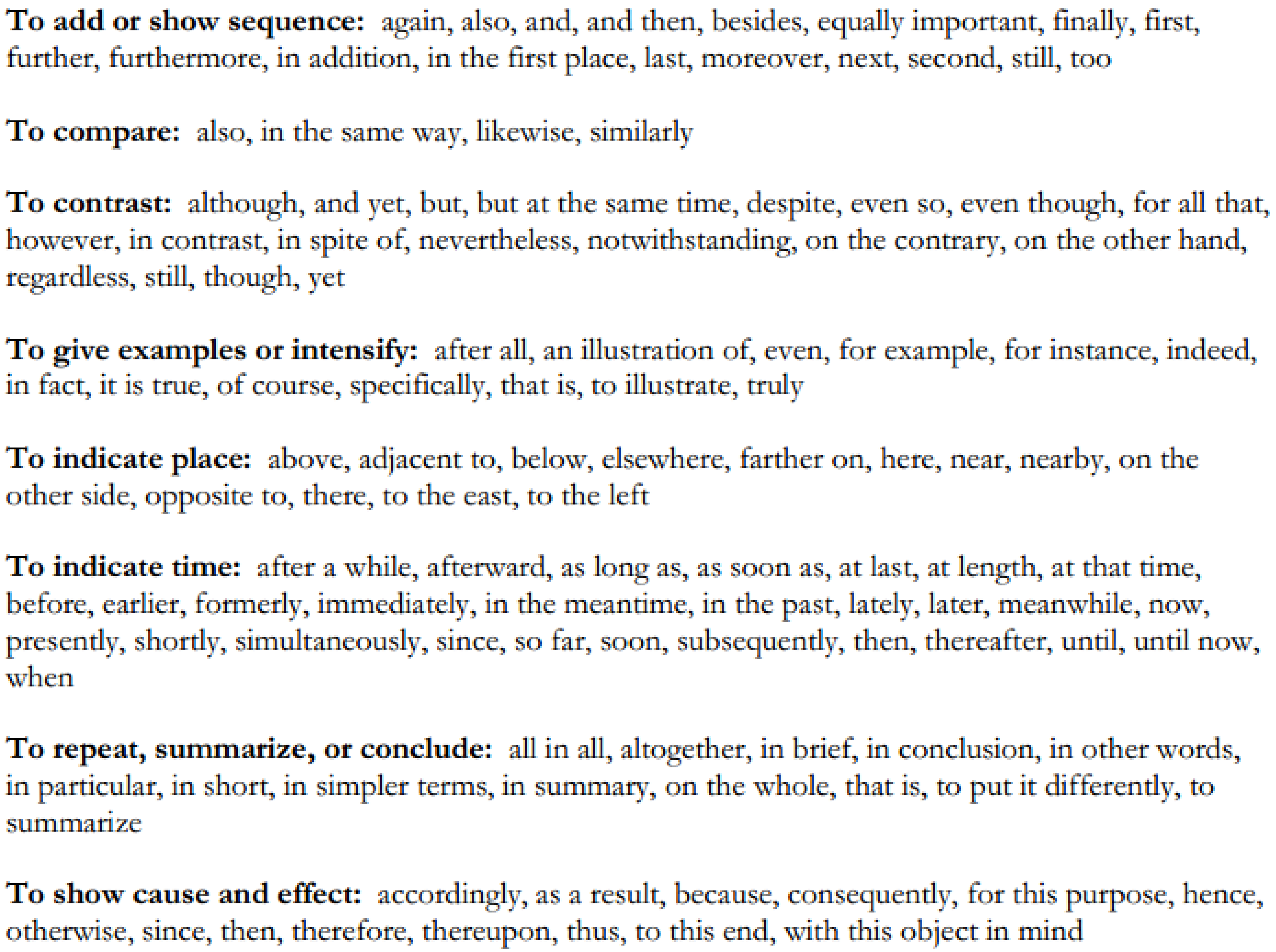
Pointing Words

The authors of [6] attempted to improve the classification accuracy of these mental tasks by using the Kullback-Leibler (KL) divergence as a distance metric in the k-nearest neighbor (k-NN) classifier. However, ….

Benevides et al., ISCAS 2011

Transitional Expressions



To add or show sequence: again, also, and, and then, besides, equally important, finally, first, further, furthermore, in addition, in the first place, last, moreover, next, second, still, too

To compare: also, in the same way, likewise, similarly

To contrast: although, and yet, but, but at the same time, despite, even so, even though, for all that, however, in contrast, in spite of, nevertheless, notwithstanding, on the contrary, on the other hand, regardless, still, though, yet

To give examples or intensify: after all, an illustration of, even, for example, for instance, indeed, in fact, it is true, of course, specifically, that is, to illustrate, truly

To indicate place: above, adjacent to, below, elsewhere, farther on, here, near, nearby, on the other side, opposite to, there, to the east, to the left

To indicate time: after a while, afterward, as long as, as soon as, at last, at length, at that time, before, earlier, formerly, immediately, in the meantime, in the past, lately, later, meanwhile, now, presently, shortly, simultaneously, since, so far, soon, subsequently, then, thereafter, until, until now, when

To repeat, summarize, or conclude: all in all, altogether, in brief, in conclusion, in other words, in particular, in short, in simpler terms, in summary, on the whole, that is, to put it differently, to summarize

To show cause and effect: accordingly, as a result, because, consequently, for this purpose, hence, otherwise, since, then, therefore, thereupon, thus, to this end, with this object in mind

Taken from:
http://composition.la.psu.edu/resources/graduate-writing-center/handouts-1/Coherence%20in%20Academic%20Writin%20Fall%202010.pdf

Common Grammatical Problems

Voice

Active voice:

We developed [a new method] for the unsupervised classification of action potentials.

Passive voice:

[A new method] for the unsupervised classification of action potentials **was developed** *(by us)*.

Active Voice vs. Passive Voice

- Active voice is usually more direct, resulting in shorter, easier-to-read sentences
- Active voice is usually more precise
- Passive voice can be more boring to read

BUT….

- There are no set rules for which voice to use
- A good rule of thumb is to ***use active voice whenever possible***

When to Avoid Passive Voice

- When it confuses the meaning because the "doer" is important (e.g. in introductory sections)
  - "A new method was developed…." (By whom? By you, in this paper? By someone else, in the past?)
- When it makes the sentence unnecessarily longer, wordier, and more difficult to read
  - "When the chip was tested by the authors, it was discovered that there was a short to ground." (18w)

vs.

  - "We discovered a short to ground during chip testing." (9w)

When Passive Voice is Preferable

- When the object is more important than the doer
  - “Protein A is phosphorylated in pancreatic cancer cells.”
- When the doer is implied (e.g. in a Methods section)
  - “Simulated signals were constructed….Noise was added….The amplitudes were normalized to 1….Finally, the data was downsampled to 24 kHz.”

Active Voice ≠ First Person

- A power savings of 20% **was achieved** compared to the current state of the art.

- **We achieved** a power savings of 20% compared to the current state of the art.

- This device consumes 20% less power than the current state of the art.

Verb Tenses

- **Past tense**: work that has already been completed (*including the work that you are presenting in your current paper*)

- **Present tense**: “truths”

- **Future tense**: paper road map; future work

Verb Tenses

- Past tense: Work that has already been completed (*including the work that you are presenting in the current paper*)
  - “Wireless neural recording systems from the 1990s **were built** from discrete modules [7]….”
  - “We **built** an off-chip class E amplifier….”
  - “The integrated circuits **were fabricated** in a commercial 0.5-μm 3M2P CMOS process.”

Example sentences from: Harrison et al., JSSC 2007

Verb Tenses

- Present tense: “truths”
  - “Neurons **communicate** with one another using stereotyped voltage pulses known as action potentials or spikes.”
  - “A finite state machine (FSM) on the chip **implements** a robust algorithm for recovering this binary command data in the presence of glitches. The FSM first **waits** for a low-to-high transition. When this **occurs**, a timer **starts counting**. When the timer **reaches** a specified time, the binary data stream **is sampled**.”

Example sentences from: Harrison et al., JSSC 2007

Verb Tenses

- Future tense:
  - Paper road map
    - “In this paper we **will describe** the development of a mixed-signal integrated circuit….”
  - Future work
    - “This chip **will** directly **connect** to all 100 electrodes, **amplify** the neural signals from each electrode, **digitize** spikes and a selected waveform, and **transmit** the information over an RF link. Power **will be delivered** to a 5-mm coil mounted on the back of the chip using an inductive link. The entire device **will be coated** in parylene and silicon carbide to protect it from internal body fluids.”

Example sentences from: Harrison et al., JSSC 2007

For More Help…

- Visit the Graduate Writing Center!