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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR §1.53(c).

INVENTOR(S)					
Given Name (first and middle [if any])		Family Name or Surname		Residence (City and either State or Foreign Country)	
Hui Aamod Robert		Jin Khandekar McEliece		Pasadena, CA Pasadena, CA Pasadena, CA	
<input type="checkbox"/> Additional inventors are being named on the <u>0</u> separately numbered sheets attached hereto.					
TITLE OF THE INVENTION (280 characters max)					
SERIAL INTERCONNECTION OF A LOW-DENSITY GENERATOR CODE WITH A DIGITAL RECURSIVE FILTER					
CORRESPONDENCE ADDRESS					
Direct all correspondence to:					
<input checked="" type="checkbox"/> Customer Number: 20985		Place Customer Number Bar Code Label Here			
OR					
<input checked="" type="checkbox"/> Firm or Individual Name		Fish & Richardson P.C. (Southern California)			
Address		4350 La Jolla Village Drive, Suite 500 San Diego, CA 92122			
Country		United States	Telephone	(858) 678-5070	Fax (858) 678-5099
ENCLOSED APPLICATION PARTS (check all that apply)					
<input checked="" type="checkbox"/> Specification		Number of Pages	33	<input type="checkbox"/> Small Entity Statement	
<input type="checkbox"/> Drawing(s)		Number of Sheets	0	<input type="checkbox"/> Other (specify)	
METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT (check one)					
<input checked="" type="checkbox"/> A check or money order is enclosed to cover the filing fees.				FILING FEE AMOUNT (\$)	
<input type="checkbox"/> The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number:				06-1050	\$150
The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.					
<input type="checkbox"/> No.					
<input checked="" type="checkbox"/> Yes, the name of the U.S. Government agency and the Government contract number are: Grant No. CCR-9804793					

Respectfully submitted,

Signature

Name Scott C. Harris, Reg. No. 32,030

Date May 18, 2000

Telephone No. (858) 678-5070

Docket No. 06618/637001/CIT3220
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Date of Deposit XMay 18, 2000

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Typed Name of Person Signing XDerek W. Norwood

PROVISIONAL APPLICATION FOR PATENT

under

37 CFR §1.53(c)

TITLE: SERIAL INTERCONNECTION OF A LOW-DENSITY
GENERATOR CODE WITH A DIGITAL RECURSIVE
FILTER

APPLICANT: HUI JIN, AAMOD KHANDEKAR AND ROBERT
MECLIECE

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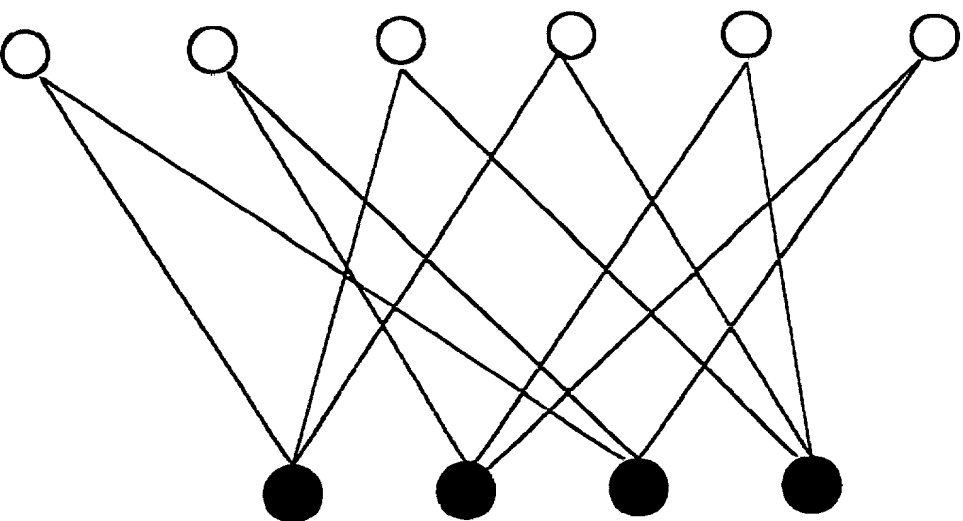
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Turbo-like Code Design: The game near channel capacity

Hui Jin

Low-Density Parity-Check Codes

Gallager 1963



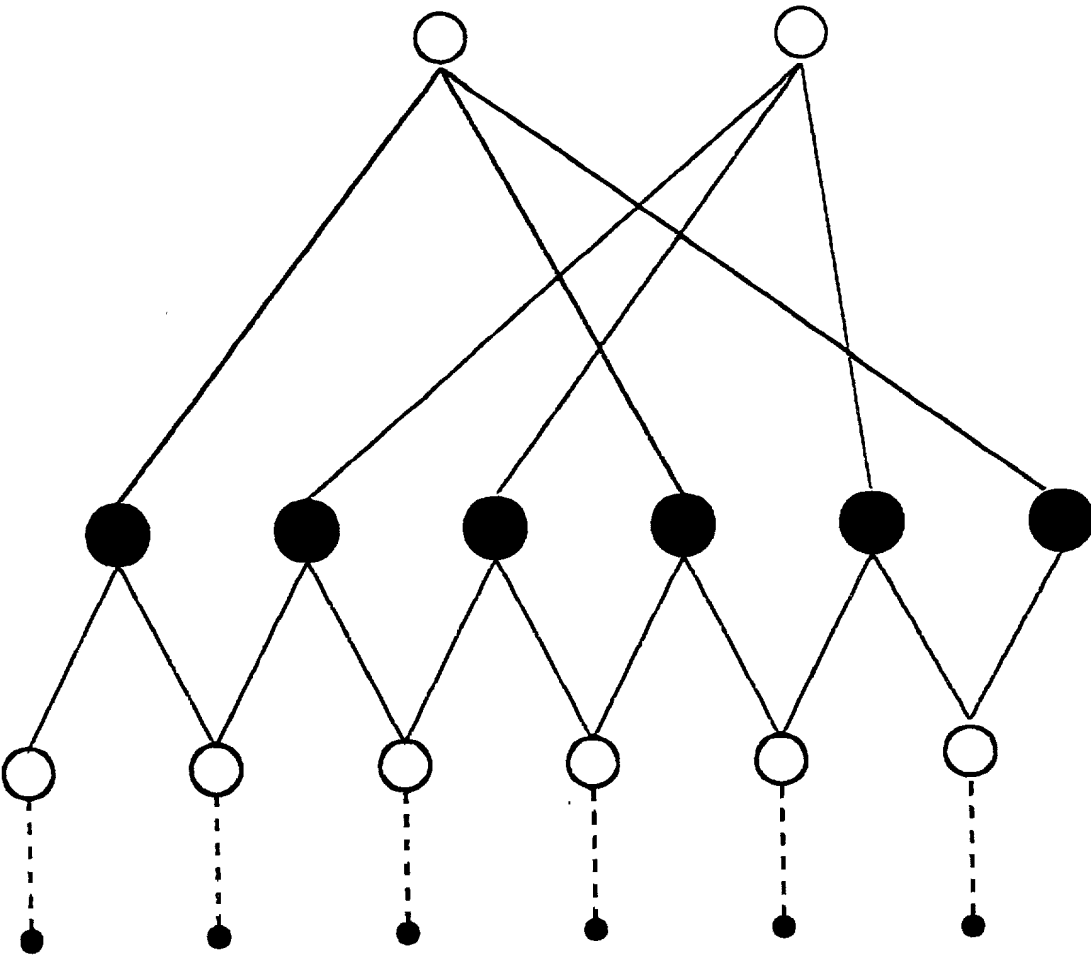
Irregular LDPC Codes

- Idea: Introduce irregularity into degree of variable nodes and check nodes.
- Binary erasure channel: Luby, Mitzenmacher, Shokrollahi, Spielman, 1997.
- AWGN, Binary symmetric channel: Richardson, Urbanke, Shokrollahi, 1999.

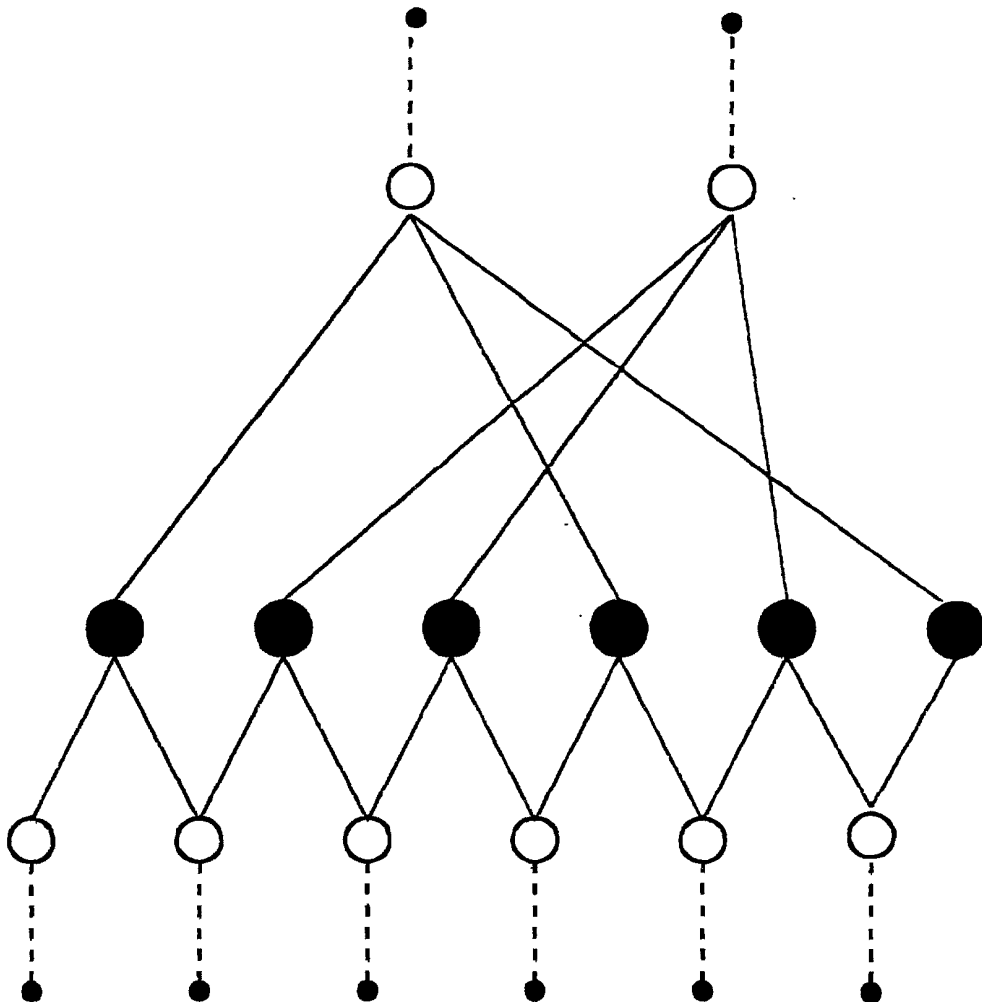
Drawback of LDPC codes

Although decoding complexity is linear, natural encoding complexity is quadratic.

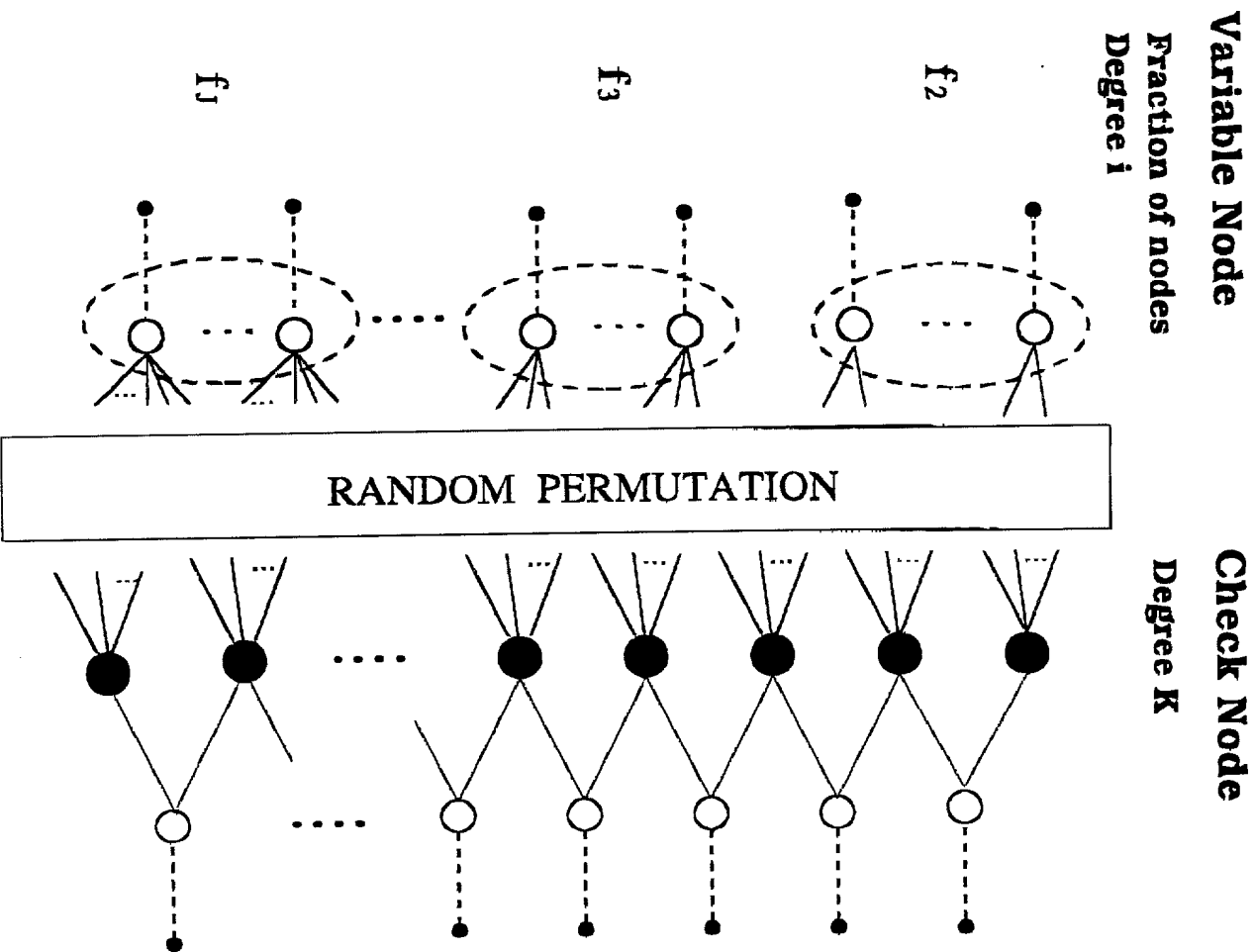
Review of RA codes



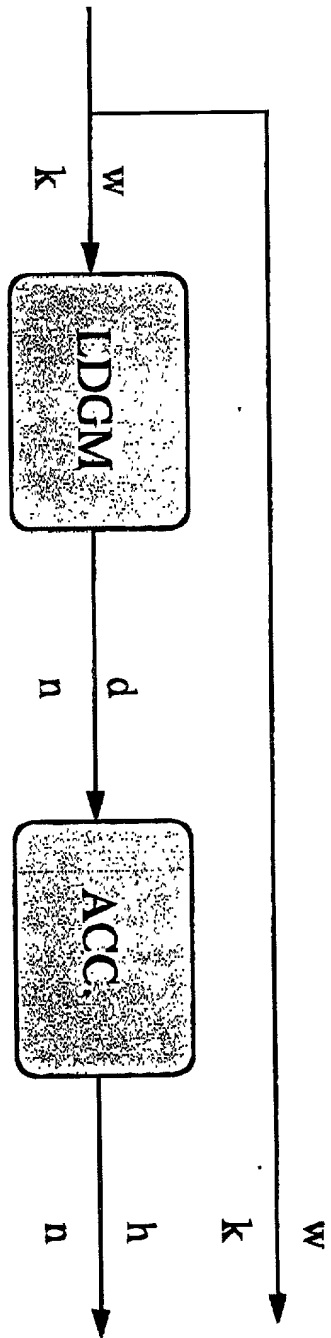
RA code as an LDPC code



Irregular RA codes: Graph Representation



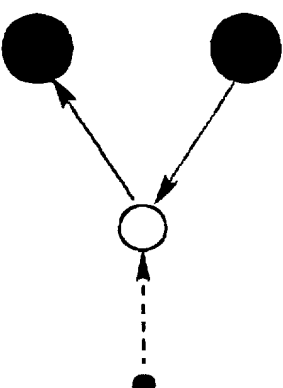
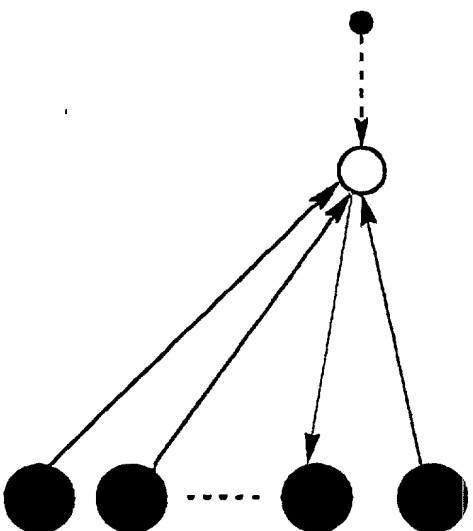
Irregular RA codes: Structure



Problem Specification

- Given a degree profile, how to compute the iterative decoding threshold?
- How to optimize this degree profile, i.e. find a profile giving the best threshold?

Message Passing: Variable nodes

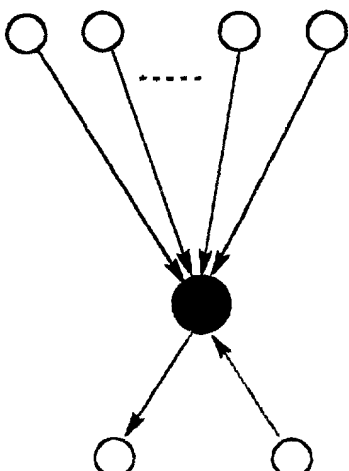
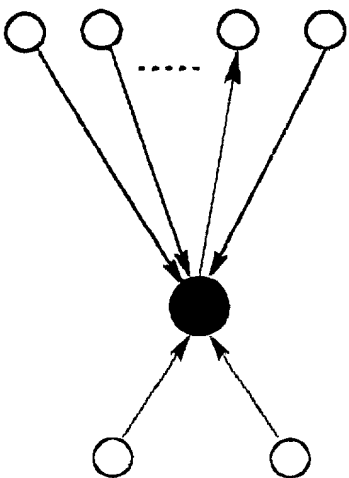


- The output message depends on the incoming messages from the other neighbors.

- Assume messages are log-likelihood ratios, i.e. $M = \ln \frac{p(0)}{p(1)}$,

$$M_{out} = \sum_{i \in in} M_i.$$

Message Passing: Check nodes

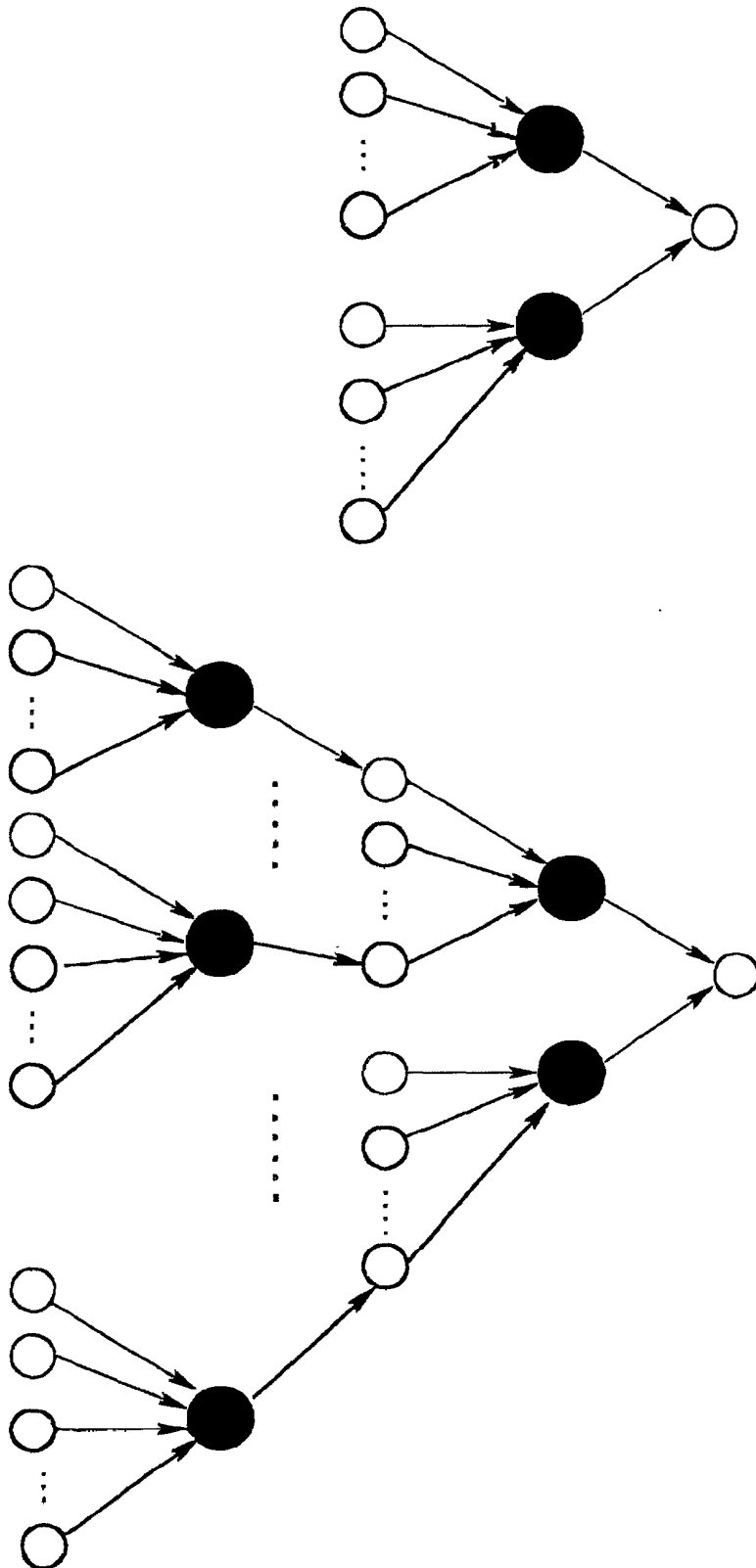


- The output message depends on the incoming messages from the other neighbors.

- $(p_0 - p_1)_{out} = \prod_{i \in in} (p_0 - p_1)_i$, i.e.,

$$\tanh \frac{M_{out}}{2} = \prod_{i \in in} \tanh \frac{M_i}{2}.$$

Computation Tree



Density Evolution

Assume $P(M)$ is the probability density function of random variable M , we can track the density evolution by the message passing rule.

- Variable nodes:

$$P(M_{out}) = P(M_{i_1}) \otimes P(M_{i_2}) \dots \otimes P(M_{i_k}),$$

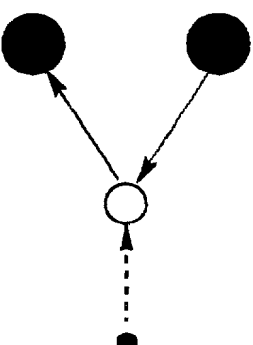
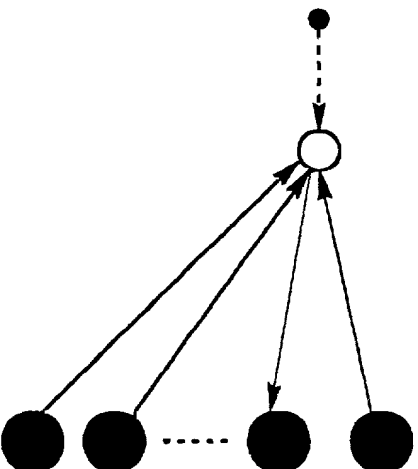
- Check nodes: similar.

Simplification

Assume the messages from check nodes to variable nodes are *Gaussian distributed*.

- Approximation is good at variable nodes, poor at check nodes. But it's OK for design purpose.
- With a consistency condition ($2\mu = \sigma^2$), we can just propagate the mean μ .

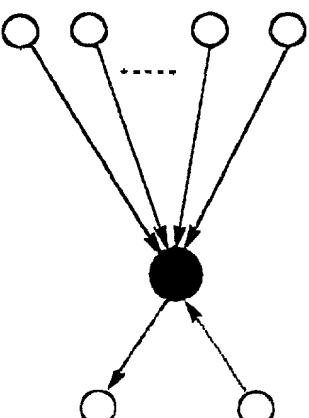
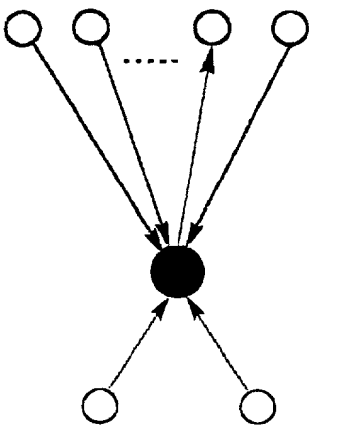
Mean Propagation



At variable nodes,

$$\mu(M_{out}) = \sum_{i \in in} \mu(M_i)$$

Mean Propagation



At check nodes,

$$E[\tanh \frac{M_{out}}{2}] = \prod_{i \in in} E[\tanh \frac{M_i}{2}],$$

$$\mu(M_{out}) = \phi^{-1}(E[\tanh \frac{M_{out}}{2}]),$$

where $\phi(\mu) = E_{G(\mu)}[\tanh \frac{m}{2}]$.

Recursion

Let $w_l = E[\tanh \frac{m_l}{2}]$, where m_l is the message from right variable node to check node at l th iteration. We obtain $w_{l+1} = F(w_l)$, where $F(x)$ is a linear function of f_i , the degree profile.

- We require $w_l \rightarrow 1$ as l approaches infinity.
- Sufficient and necessary condition: $F(x) > x$ for any $x \in [w_0, 1)$.

Linear Programming Problem

Maximize objective function

$$\sum_i c_i x_i$$

under condition

$$F(x) \leq b, \quad \forall x \in [u_0, 1).$$

Design Result I

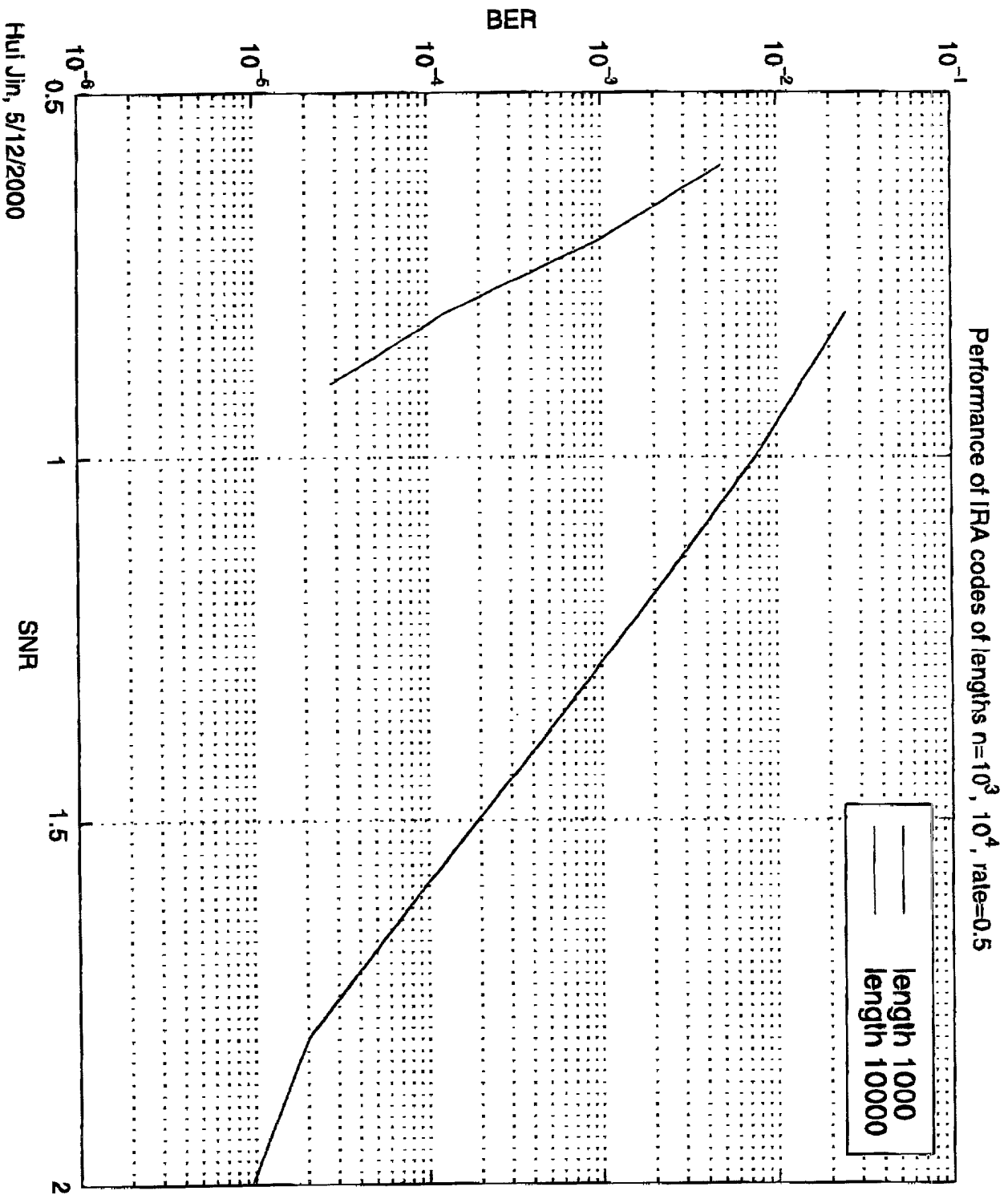
rate=1/3, capacity = -0.495 (dB).

k	2	3	4
f_2	0.278010	0.234698	0.218052
f_3	0.296168	0.256297	0.278317
f_5		0.193071	
f_6	0.425822	0.036196	0.169094
f_{10}			0.183948
f_{11}			0.011995
f_{12}		0.054441	
f_{13}		0.225297	
f_{27}			0.133492
f_{28}			0.005100
σ_{GA}	1.1840	1.2415	1.2615
σ^*	1.1981	1.2607	1.278
$(\frac{E_b}{N_0})^*(dB)$	0.190	-0.250	-0.371

Design Result II

rate $\doteq 1/2$, capacity $\doteq 0.19$ (dB).

k	8	8
f_2		0.232757
f_3	0.667892	0.314727
f_7		0.252341
f_8		0.0336604
f_{11}	0.058720	
f_{12}	0.216137	
f_{18}		0.0962193
f_{20}		0.0303382
f_{46}	0.031812	
f_{48}	0.025439	
f_{55}		0.0118597
f_{58}		0.0280972
σ^*	0.9589	0.972
$(\frac{E_b}{N_0})^*(dB)$	0.34	0.26



Forward Error Correction for the Internet

Aamod Khandekar
Robert McEliece

Introduction to Channel Coding

- Aim: Reliable transmission of data over noisy channels.
- Idea: Introduce redundancy in the data.
- Parameters of interest:
 - Probability of error.
 - Rate of transmission.

Channel Models

- Only consider transmission of binary data.
- Examples of channel models:
 - The Binary Symmetric Channel(BSC)
 - The AWGN Channel
 - The Binary Erasure Channel(BEC)
- Internet with IP - nicely modeled as an erasure channel.

Capacity of a Channel

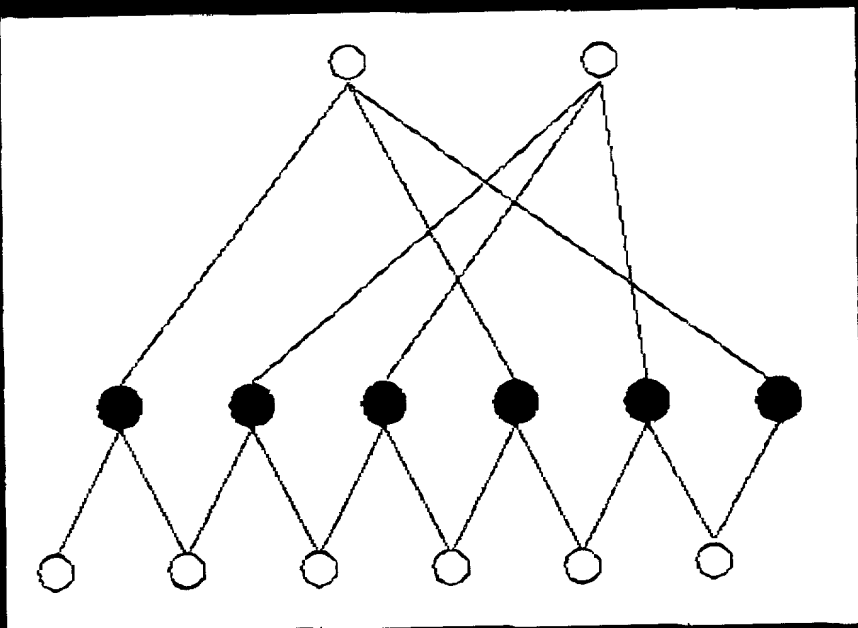
- Shannon showed (in 1948):
 - Associated with every channel is a number called the capacity of the channel.
 - It is the maximum rate at which information can be transmitted “reliably” over the channel.
 - *Random Codes* achieve capacity.

Linear Block Codes

- Code: A subset of the set of possible messages, called the set of codewords.
- Block code: Data is partitioned into blocks of fixed size, say n .
- Binary (n,k) -linear block code:
 - Codewords form a linear subspace of dimension k of the set of possible messages.
 - Rate of the code is k/n .

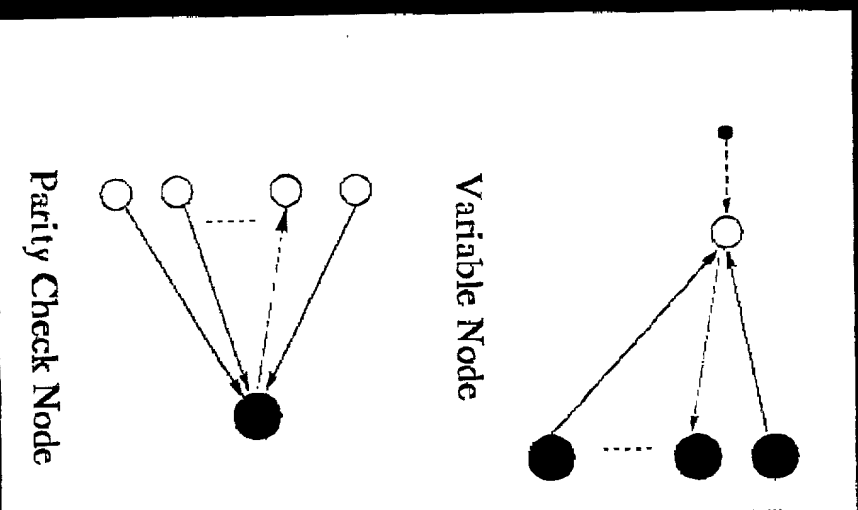
The Tanner Graph

- A linear code can be represented as a set of *parity checks*.
- The set of parity checks can be represented in a *bipartite graph*, called the Tanner graph of the code.



The Decoding Algorithm

- Iterative *Message passing decoders* work on Tanner graphs.
- Messages passed are often *log-likelihoods*.
- Outward message depends on incoming messages along all *other edges*.

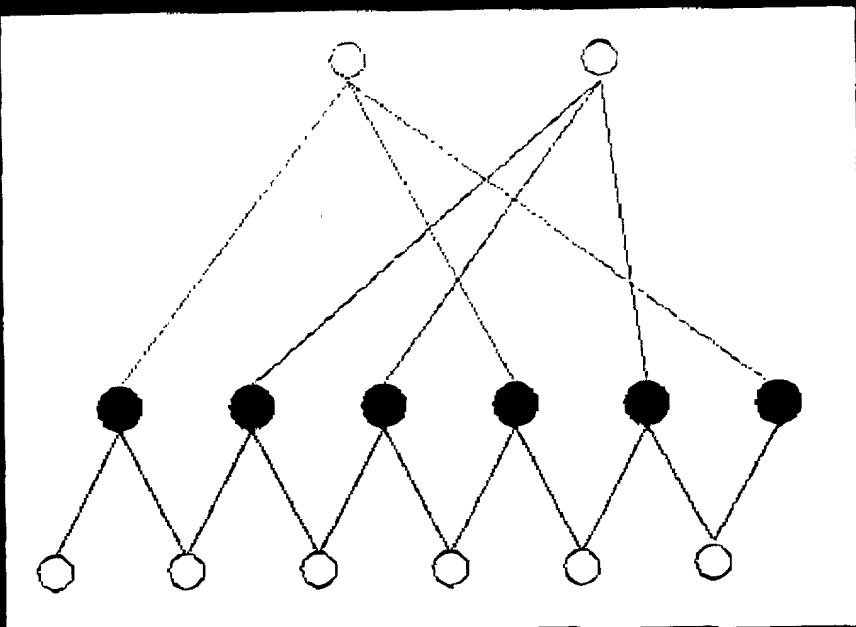


Decoding on the Erasure Channel

- Only three types of messages:
 - Zeros, ones and erasures.
- At variable nodes:
 - Outgoing message is equal to any non-erasure incoming message.
- At check nodes:
 - Outgoing message is the sum of incoming messages if they are all non-erasures.

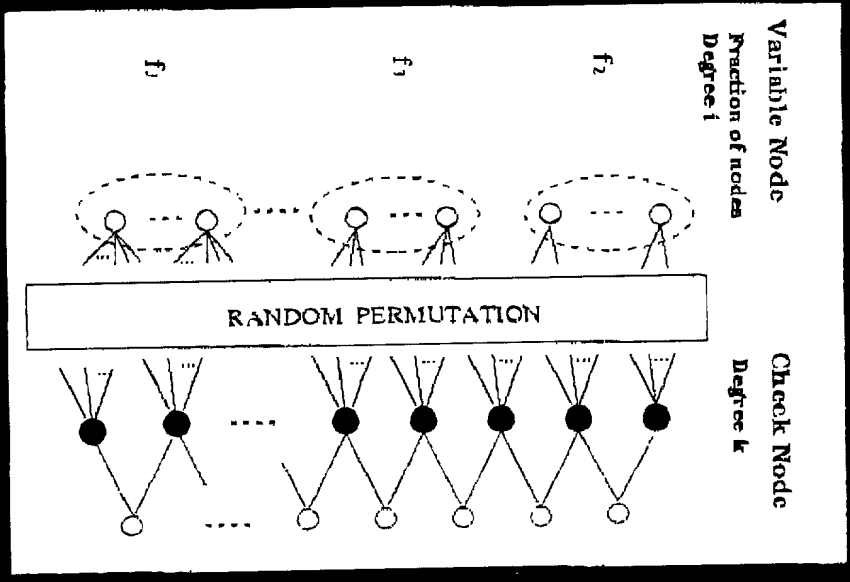
Repeat-Accumulate(RA) Codes

- Consist of three blocks:
 - A repetition (by q) block.
 - A permutation block.
 - An accumulator block.
- Simplified versions of *Turbo codes*.
- Rate $1/(q+1)$.



Irregular RA Codes

- Idea: Not to repeat all bits the same number of times.
- Get a *degree sequence* for the leftmost nodes in the graph.
- *Design* good degree sequences.



Results

- Degree sequences can be designed to give very good performance on the AWGN channel with iterative decoding.
- There exist degree sequences that provably achieve capacity on the binary erasure channel, also with iterative decoding.
- Encoding is easy and fast.

Applications

- Transmission of large data files over the internet.
- Instead of retransmissions, as with TCP, use erasure coding to recover lost packets.
- Speeds up data transfers.
- Saves bandwidth.